



The role of grid resolution, latent heat release, and initialisation time on the simulation of Storm Éowyn and its impacts

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Abstract. Extratropical cyclones are primary drivers of damaging winds, heavy precipitation, and coastal flooding in the mid-latitudes. Accurately predicting their track and intensity is important for early warnings, but rapidly-deepening extratropical cyclones can pose a severe forecasting challenge due to their explosive growth, fast propagation, and extreme surface weather conditions. Capturing this rapid development in numerical weather prediction model simulations depends on grid resolution, initialisation time, as well as on the representation of small-scale diabatic processes, in particular latent heating (LH). In this study, we analyse how these factors influence the track, intensity, and surface hazards of the explosively-deepening North Atlantic Storm Éowyn, which occurred in January 2025 and caused extensive wind damage across the British Isles. Using the ICOsahedral Nonhydrostatic (ICON) model in limited-area mode, we perform sensitivity experiments with varying horizontal resolution and forecast lead time. Additionally, we run experiments with scaled LH to isolate its specific role in the development of this high-impact cyclone. The ICON simulations reveal that horizontal resolution plays a critical role for cyclone intensity, with finer grid spacings producing lower central mean sea level pressure values that align more closely with observations. The higher cyclone intensity at higher resolution is linked to a stronger vertical potential vorticity (PV) tower and translates into amplified surface winds and precipitation. With increased resolution, cloud-diabatic processes produce higher low-level PV values, which are associated with more intense surface wind speeds. When LH is fully suppressed, the resulting cyclone is significantly weaker, indicating a diabatic deepening contribution to cyclone intensity of 12 % to 53 %, depending on the forecast initialisation time. The cyclone in the experiments without LH exhibits a distinct northward shift and reduced eastward propagation, such that the cyclone misses the British Isles. The reason for this behaviour in the experiments without LH is an altered steering flow due to a weakened upper-level jet and the absence of downstream ridge building. Finally, initialisation time introduces a non-monotonic sensitivity: initialisation several days prior to cyclogenesis generally yields an underestimation of cyclone intensity and surface winds. Simulations with specific initialisation times substantially underestimate intensity across different model resolutions, highlighting a high sensitivity to early-stage initial conditions and numerical challenges in the convective 'grey zone'. Nevertheless, considering the operational ECMWF ensemble, the spread in cyclone intensity includes the observed evolution already when initialised five days before cyclogenesis. While this study examines a single high-impact cyclone, the large effects of grid resolution, initialisation time, and LH on its representation emphasizes the complex challenges in modelling explosive cyclones and highlights how sensitive these forecasts are to the specific configuration of the simulations.



1 Introduction

Extratropical cyclones (ETCs) constitute the dominant synoptic-scale weather system in mid-latitudes and are responsible for a large fraction of societally impactful weather events, including extreme winds, heavy precipitation, snowstorms, and coastal storm surges (e.g., Browning, 2004; Catto and Pfahl, 2013; Hewson and Neu, 2015). While these systems typically form along large-scale temperature gradients via baroclinic instability (e.g., Charney, 1947; Eady, 1949), the release of latent heating (LH), which occurs on smaller scales during cloud and precipitation formation, can heavily intensify cyclones during their development stage (e.g., Davis and Emanuel, 1991; Binder et al., 2016). The severity of the impact of an ETC is ultimately determined by four critical dimensions: its path, intensity, (mesoscale) structural evolution, and (local) associated surface hazards, in particular wind speed and precipitation. Even minor changes in the path of a cyclone or a slight reorganization of its mesoscale features can drastically change the respective surface hazards (e.g., Froude et al., 2007; Doyle et al., 2014; Eisenstein et al., 2022). Consequently, accurately forecasting these aspects of ETCs with numerical weather prediction (NWP) models requires a thorough understanding of how cyclone evolution is influenced by the model configuration, such as, for example, horizontal grid spacing, the time of forecast initialisation, and the representation of sub-grid scale physical processes, including LH due to cloud formation.

Increasing horizontal model resolution generally improves simulated ETC tracks and mesoscale structures (e.g., Jung et al., 2006; Champion et al., 2011; Jung et al., 2012; Booth et al., 2018; Priestley and Catto, 2022). In particular, higher resolution consistently enhances localized features, leading to higher vorticity, stronger low-level winds, and amplified precipitation rates (e.g., Champion et al., 2011; Booth et al., 2018; Schemm, 2023). Kilometre-scale resolution captures mesoscale vortices embedded in the cyclone core (e.g., Leutwyler and Schär, 2019; Zeitzen et al., 2025) and embedded convection within warm conveyor belts. The resulting change in the conveyor belt ascent behaviour directly impacts LH and the associated diabatic PV modification in ETCs (Oertel et al., 2019). However, the broader dynamical implications remain nuanced: while higher resolution increases the frequency of explosive deepening rates (e.g., Schemm, 2023), overall deepening sensitivity and the relative dynamical importance of LH do not necessarily scale monotonically with grid spacing (e.g., Flack et al., 2021; Choudhary and Voigt, 2022).

Diabatic processes often contribute substantially to ETC deepening, with LH typically acting as the major source of lower tropospheric potential vorticity (PV) production in the cyclone centre (Attinger et al., 2021). However, the magnitude of this contribution varies strongly between cases (e.g., Wernli and Gray, 2024). Several diagnostics exist to estimate the contribution of LH to cyclone deepening, such as the pressure tendency equation (e.g., Fink et al., 2012; Christ et al., 2026) and PV-based approaches (e.g., Davis and Emanuel, 1991; Rossa et al., 2000; Büeler and Pfahl, 2017). Complementary to these approaches, the role of LH can be quantified through real-case numerical sensitivity experiments where LH is artificially reduced or completely deactivated (so-called “suppressed LH experiments”, see Wernli and Gray, 2024, their Sect. 4.2). Various methods exist for suppressing LH, including initialising relative humidity throughout the model domain with uniformly low values (Cho and Cao, 1998; Lackmann et al., 2026), disabling parameterised convection and cloud microphysics (e.g., Kuo and Reed, 1988; Kuo and Low-Nam, 1990), or explicitly setting LH constants to zero (e.g., Stoelinga, 1996; Büeler and Pfahl,



2017; Robinson et al., 2026). By comparing modified simulations with unperturbed control experiments, these approaches provide a controlled framework for quantifying the contribution of LH to the evolution of cyclone intensity, as well as its path, structure, and surface weather.

Initialisation time and medium-range predictability are tightly linked for ETCs as the largest forecast error growth is often found during cyclogenesis, when small initial-state differences amplify rapidly into errors in the track and intensity of ETCs, and their associated wind and precipitation fields (e.g., Doyle et al., 2019; Rodwell and Wernli, 2023). In the medium range, forecasts generally maintain useful skill for cyclone occurrence and track; however, intensity, rapid cyclone deepening, and propagation speed are often less well predicted (e.g., Froude et al., 2007; Büeler et al., 2023). Real-case simulations of ETCs show that changing the forecast start time alone can substantially alter cyclone structure, motion, intensity and associated surface hazards (e.g., Pradhan et al., 2021). Adjoint and ensemble studies further revealed that the mesoscale moisture distribution, frontal structure, and PV anomalies at initialisation time strongly influence the evolution of ETCs, as well as their associated high winds and precipitation, during the first two days of the simulation (e.g., Doyle et al., 2019).

Several studies have looked at how grid spacing, LH, or initialisation time affect high-impact ETCs. However, a systematic investigation into the individual and combined influences of these numerical simulation aspects on cyclone intensity, track, structure, and associated surface weather is lacking. This study addresses this gap by running a large suite of sensitivity experiments on Storm Éowyn, a rapidly deepening, high-impact ETC that hit the British Isles in January 2025.

Storm Éowyn developed into UK's most powerful wind storm for over a decade. Specifically in Northern Ireland, Éowyn was the most intense cyclone since the Boxing Day Storm of 26 December 1998 (Suri et al., 2025). Along the coastline and over land, it resulted in widespread damage across Scotland, Northern Ireland, and parts of Ireland, leading to a total halt of major transport services, massive power outages for around a million homes, extensive property damage, and two reported fatalities (e.g., Met Office Press Office, 2025; Chan et al., 2025; Cha et al., 2025). Storm Éowyn set all-time wind speed records across Ireland, with wind gusts of up to 51 m s^{-1} at the weather station in Mace Head on the west coast of Ireland on 24 January 2025 (Met Éireann, 2026).

In this study, we use the ICOSahedral Nonhydrostatic (ICON) model (Zängl et al., 2015) in its limited area mode to investigate the sensitivity of the development of Storm Éowyn to model resolution and initialisation time. Given the explosive development of the cyclone (Suri et al., 2025), it is also a great candidate to investigate the role of LH by conducting suppressed LH experiments.

The three central research questions guiding this study are:

1. What is the effect of varying horizontal resolution (grid spacings from 50 to 3 km) on cyclone intensity, track, and near-surface wind speeds?
2. How does LH influence the structural evolution, intensity, and near-surface winds of Storm Éowyn?
3. How sensitive are the simulated cyclone characteristics to the initialisation time, and how does this sensitivity depend on horizontal resolution and the representation of LH?



The paper is structured as follows: Section 2 introduces the datasets, model setup, and methods used in this study, followed by an overview of Storm Éowyn's life cycle in Sect. 3. The sensitivity of the cyclone to different spatial resolutions is then explored in Sect. 4., while Sect. 5 focuses on the impact of LH on its intensification. Finally, in Sect. 6 we analyse the sensitivity of the simulations to the initialisation time, also considering operational ensemble forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF). The study finishes with the summary and conclusions in Sect. 7.

2 Data and methods

2.1 ERA5 reanalysis and IFS analysis

In this study, we use the ERA5 reanalysis data (Hersbach et al., 2020) from ECMWF to study the synoptic-scale evolution of Storm Éowyn and as a reference for comparison with the different ICON simulations. ERA5 is produced using the model cycle Cy41r2 of the Integrated Forecasting System (IFS; operational in 2016) and we use hourly data interpolated on a 0.25° latitude-longitude grid in the Northern Hemisphere.

Given their higher resolution than ERA5, operational IFS analyses are used as initial and boundary conditions for our ICON simulations. Based on the IFS cycle Cy49r1 (operational from November 2024 to May 2026), these analyses provide global atmospheric fields at a T1279 spectral truncation, which translates to a horizontal resolution of approximately 9 km. The dataset offers a vertically comprehensive view of the atmosphere across 137 model levels and is available at 6-h intervals (at 00, 06, 12, and 18 UTC).

2.2 ICON simulations

For our process and sensitivity studies, we use ICON (Zängl et al., 2015), which is an NWP model developed in a joint effort between the German Weather Service (Deutscher Wetterdienst, DWD), the Max Planck Institute for Meteorology (MPI-M), the Karlsruhe Institute of Technology (KIT), the German Climate Computing Center (DKRZ) and the Center for Climate Systems Modeling (C2SM) at ETH Zurich. It solves the full 3D non-hydrostatic and compressible Navier Stokes equations on an icosahedral horizontal grid, using terrain-following vertical coordinates. We conduct our experiments with the ICON version 04.2025 together with the physics package for NWP (ICON-NWP) in the limited-area mode. Five different grid spacings are considered: 50, 20, 13, 7, and 3 km (details in Table 1). All simulations have the model top at 30 km and, if not specified further, are run with 90 vertical levels. They use the one-moment cloud microphysics scheme by Doms et al. (2005) and the ecRad radiation scheme (Hogan and Bozzo, 2018). Convection is parameterised for the simulations with grid spacings of 13, 20 and 50 km, using a scheme building on Tiedtke (1989) and Bechtold et al. (2008).

All simulations are initialised and driven at the lateral boundaries by IFS analyses (Sect. 2.1). For this purpose, the data is remapped to the ICON grid using the ifs2icon tool provided by DWD. The choice of using IFS analyses is motivated by their superior horizontal resolution (~ 9 km) compared to ERA5 (~ 31 km). While ERA5 was also evaluated for initial and lateral boundary conditions, simulations driven by IFS analyses produced a cyclone deepening that agreed slightly more closely with



Table 1. ICON simulation setups with different horizontal resolutions.

experiment number	approx. grid spacing (km)	ICON grid	time step (s)	regular grid (°lat/lon)	parameterised convection
1	50	R3B5	200	0.5	on
2	20	R2B7	90	0.2	on
3	13	R3B7	70	0.125	on
4	7	R3B8	35	0.05	off
5	3	R3B9	20	0.025	off

observations. An additional reason for selecting IFS analyses, despite their coarser temporal resolution, is that we found no
 125 sensitivity of the cyclone’s track and deepening to the boundary condition update frequency (tested with ERA5 at 1 h, 3 h, and
 6 h intervals).

The simulation domain encompasses a large region from the Gulf of Mexico across the North Atlantic to the Norwegian
 Sea (Fig. 1). The domain is defined on a rotated grid with the north pole at 29°N, 180°E, spanning 60° in latitude and 98° in
 longitude (roughly 6700 km × 10200 km). The rather large domain ensures that the entire track of Storm Éowyn is captured
 130 in a single, continuous integration. By choosing the model domain such that the cyclone is far from the lateral boundaries, we
 effectively isolate its core dynamics from potential boundary update artifacts. This experimental setup is also critical for our
 subsequent suppressed LH experiments (Sect. 2.3), as it ensures minimal influence of the lateral boundaries on the modified
 cyclone dynamics.

2.3 LH experiments

135 As mentioned in the introduction, to investigate the impact of LH on the development of Storm Éowyn, we perform experiments
 in which we modify the impact of LH due to cloud processes on the temperature tendencies. A similar approach has been used
 in several previous studies to quantify the impact of LH on the evolution of ETCs (e.g. Kuo and Reed, 1988; Stoelinga, 1996;
 Büeler and Pfahl, 2017, 2019; Robinson et al., 2026). More specifically, we modify the temperature tendencies due to LH in
 the cloud microphysics, convection, and saturation adjustment schemes by multiplying the LH by a factor α . Simulations were
 140 performed with values of α equal to 1.25, 1.0, 0.5, 0.1 and 0.0, with $\alpha = 0.0$ referred to as the “no LH experiment”, while $\alpha =$
 1.0 corresponds to the control simulation. With $\alpha = 1.25$ we also include simulations with artificially enhanced LH.

2.4 Cyclone tracking

The hourly cyclone tracking with data from ERA5, IFS analyses, and the ICON simulations is based on mean sea level pressure
 (SLP) minima. Instead of using a generic cyclone tracking algorithm (e.g., Sprenger et al., 2017), we designed a simple feature
 145 tracking tool, which only tracks the specific cyclone of interest. The tool is initialised at a specific time t (typically taken around



Figure 1. Domain used for the limited area simulations of Storm Éowyn (blue shading) and track of Storm Éowyn as represented in ERA5 reanalyses (see Fig. 2 for more information about the track).

the time of maximum cyclone intensity) and a rectangular bounding box ($[\text{lat}_{\min}, \text{lat}_{\max}], [\text{lon}_{\min}, \text{lon}_{\max}]$). The position of the cyclone centre at time t corresponds to the minimum SLP within the box. From this anchor point, the algorithm extends the track backward and forward in time to capture the genesis of the cyclone as well as its decay. For the first two time steps around the start date ($t - 1; t + 1$) when the direction of propagation is still unknown, the tool identifies the lowest SLP value in a box
 150 $(\pm 3.5^\circ \text{ latitude}; \pm 4^\circ \text{ longitude})$ centred at the cyclone's position at t . For subsequent time steps, the tool first extrapolates the cyclone's position based on its previous propagation direction and speed and then places a smaller search box ($\pm 2^\circ \text{ latitude}; \pm 3^\circ \text{ longitude}$) around this extrapolated location. It identifies all local SLP minima in this box whose value deviates by less than 5 hPa from the core pressure at the previous time step. Among these candidates, the algorithm then selects the local minimum with the lowest SLP. As a safeguard in cases where the cyclone rapidly alters course or weakens – causing the aforementioned
 155 procedure to fail – the algorithm extends the search box ($\pm 3.5^\circ \text{ latitude}; \pm 4^\circ \text{ longitude}$) and selects the absolute SLP minimum to prevent the track from breaking.

In the following, the cyclone SLP minimum at a given time step is referred to as SLP^* , while the minimum SLP^* along an entire cyclone life cycle is referred to as $\text{SLP}_{\min}^*$.

2.5 Operational IFS ensemble

160 In order to investigate the predictability of Storm Éowyn, we consider operational ECMWF ensemble forecasts based on the IFS cycle 49r1, which became operational in November 2024 with a horizontal resolution of 9 km (Roberts et al., 2024). Ensemble forecasts are started twice daily (00 UTC, 12 UTC) with 50 members, in which small perturbations are applied to the initial conditions and stochastic perturbations are introduced to the parameterisation tendencies during model integration.

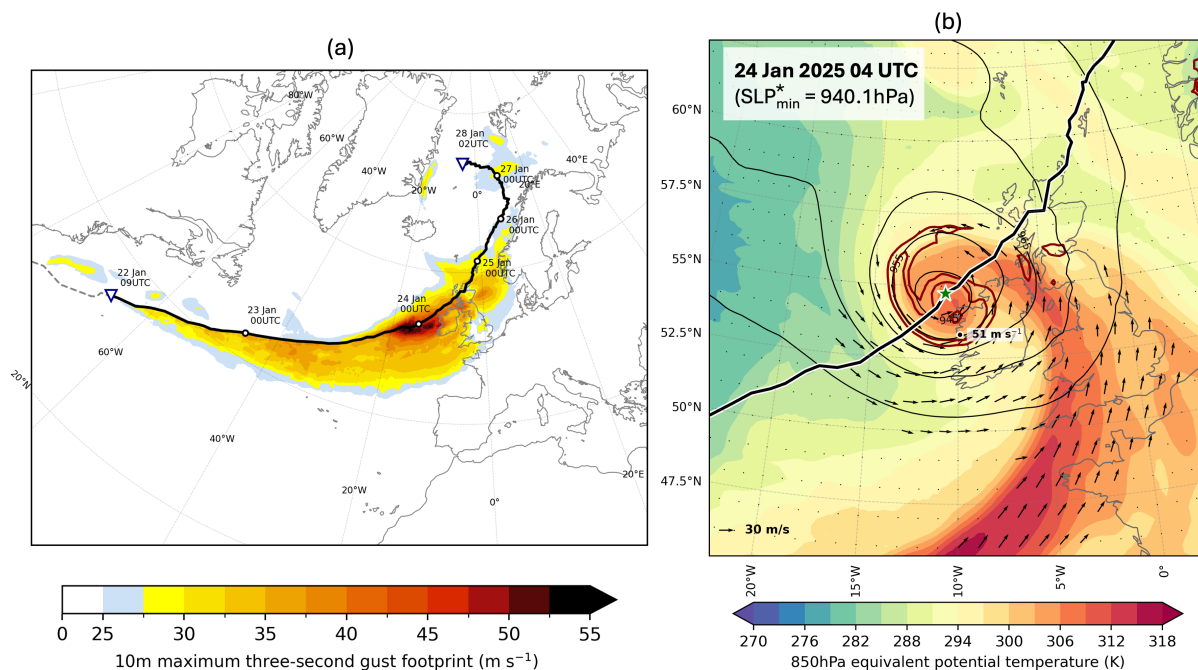


Figure 2. (a) Track of Storm Éowyn in January 2025 (black line) and associated 10 m maximum three-second gust footprint (shading; in m s^{-1}). Triangle markers show the start and end of the cyclone track, based on criteria of Sprenger et al. (2017). The grey dashed line corresponds to a manual extension of the early stage of the cyclone, when it did not fulfil the closed-contour criteria of Sprenger et al. (2017) but could still be identified as a local SLP minimum. (b) Stage of maximum intensity of Storm Éowyn (at 04 UTC on 24 January 2025) with equivalent potential temperature at 850 hPa (shading), SLP (black contours for 945, 955, 965, 975, 985 hPa), 700-900 hPa mean PV (red contours for 1.5, 2, 3 PVU), and 925 hPa wind vectors (black; shown for wind speeds $> 25 \text{ m s}^{-1}$). The thick blue line shows the track and the green star the position of the cyclone centre at the valid time (SLP*_{min}). The black marker over Ireland shows the position of the Mace Head weather station, which measured a new all-time wind gust record of 51 m s^{-1} . All analyses in this figure are based on ERA5.

For each initialisation, forecasts are archived every 6 h until a lead time of 15 d on a horizontal grid with a resolution of 0.25° .

165 From these ensemble forecasts, we use SLP for tracking (Sect. 2.4) and the 10 m wind gusts to quantify surface hazards.

3 Overview of high-impact Storm Éowyn

As described in Suri et al. (2025), Storm Éowyn developed on 22 January 2025 over the western North Atlantic, propagated rapidly eastwards towards Europe while undergoing rapid deepening. The cyclone reached its peak intensity in the early morning of 24 January west of Ireland and impacted the British Isles during its passage from 24-25 January 2025 (Fig. 2a).

170 After making landfall in northern Scotland in the afternoon on 25 January, the cyclone propagated along the coast of Norway and eventually decayed on 28 January just southwest of Svalbard. Based on the cyclone tracking criteria of Sprenger et al. (2017)—where track start and end times require at least one closed SLP contour of $+0.5 \text{ hPa}$ around the SLP*—the cyclone

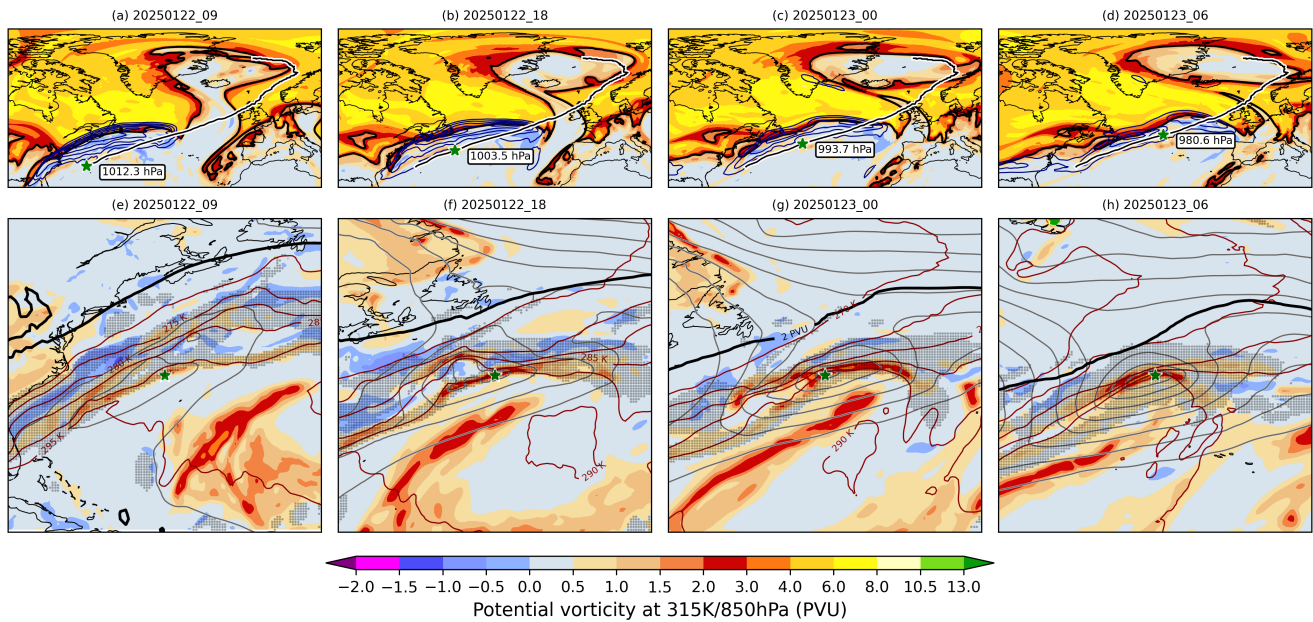


Figure 3. Formation stage of Storm Éowyn in January 2025. (a-d) PV at 315 K (shading, in PVU), cyclone track of Éowyn (black line), position of the cyclone at corresponding time (green star), 2 PVU contour at 315 K denoting the tropopause (black thick contour), and 300 hPa wind speed (blue contour, 60, 70, 80, 90, 100, 110, 120 m s⁻¹). (e-h) PV at 850 hPa (shading, in PVU), SLP (grey contours, from 970 to 1020 hPa in steps of 5 hPa), potential temperature at 950 hPa (dark red contours), 2 PVU contour at 315 K denoting the tropopause (black thick contour), and relative humidity > 90 % (grey dots).

had a rather long lifetime of 5 days and 18 hours. However, cyclone lifetime depends strongly on the tracking method, dataset, and spatial resolution used, and may differ from values reported in other studies (e.g., Priestley and Stephenson, 2025).

175 Preceding the cyclone's genesis, a cold air outbreak across the Great Plains took place from 18 January on, which continued for several days and contributed to strong baroclinicity over the western North Atlantic (National Weather Service, 2025; Suri et al., 2025). At 09 UTC on 22 January, south of an exceptionally strong upper-level jet with wind speeds at 250 hPa exceeding 110 m s⁻¹ (Fig. 3a), the genesis of Storm Éowyn occurred off the east coast of North America, with a SLP* of 1012 hPa (Fig. 4).

180 Storm Éowyn then propagated rapidly northeastward across the North Atlantic and stayed south of the jet for several hours (Fig. 3a-c), raising the question whether the cyclone developed as a so-called 'diabatic Rossby wave' (DRW; Wernli et al., 2002; Moore and Montgomery, 2005). Following the criteria of Boettcher and Wernli (2013), a cyclone is classified as a diabatic Rossby wave when it (1) is a low-level system with a cyclonic circulation mostly confined below 700 hPa, (2) is located within a strong baroclinic zone, (3) is accompanied by strong LH release just downstream of the cyclone centre where moist air ascends over the baroclinic zone, and (4) propagates rapidly along this zone via a mechanism that involves the continuous re-generation of the cyclone via diabatic PV production in the region of LH release. Investigating these criteria

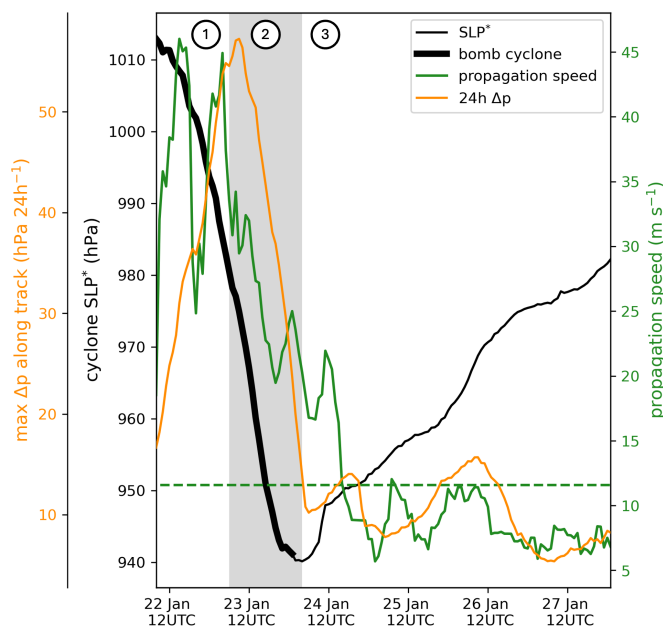


Figure 4. Evolution of the SLP* of Storm Éowyn (black line, hPa), maximum 24 h deepening rate (orange, hPa 24 h⁻¹), and cyclone propagation speed (green, m s⁻¹), based on ERA5. Numbers correspond to the life cycle stages discussed in Sect. 3, with the grey shading showing the maximum intensification phase. The dashed orange line corresponds to the threshold of 11.6 m s⁻¹, which is one of the criteria used by Boettcher and Wernli (2013) to identify DRWs.

for Storm Éowyn revealed that although criteria (1)-(3) were satisfied in the first about 24 h, i.e., in the formation and early intensification stage (Fig. 3; Fig. 4, label 1), the forcing for ascent induced by the upper levels was already slightly too strong for the system to be considered a pure DRW, indicating instead a coupled upper-level and lower-level development that is characteristic of a classic moist baroclinic cyclone. By the end of this 'hybrid' DRW stage at 06 UTC on 23 January, the SLP* had already dropped by 30 hPa (Fig. 4), fulfilling early in its life cycle the criterion of a bomb cyclone (e.g., Sanders and Gyakum, 1980).

The further explosive deepening of Storm Éowyn (label 2 in Fig. 4) was initiated by the crossing of the jet axis on 23 January (Fig. 5a-c). Located within the left exit region of a strong jet streak from 06 UTC on 23 January on, the cyclone intensified with a peak rate of 55 hPa in 24 h (Fig. 4), classifying the cyclone as an exceptionally rapidly deepening 'bomb' and placing Éowyn amongst the 1 % most strongly deepening cyclones that hit Ireland and the UK in winter since the 1959/60 season (Priestley and Stephenson, 2025).

Vertical sections across the cyclone centre show the formation of the typical vertical 'PV tower' (e.g., Hoskins and Berrisford, 1988; Čampa and Wernli, 2012; Wernli and Gray, 2024), common for intense ETCs (Fig. 5d-f): At 00 UTC on 23 January, the system was characterized in terms of PV as an isolated, diabatically produced positive PV anomaly in the lower troposphere. Over the following 24 h, while crossing the jet axis, it developed into a vertical PV tower positioned north of the strong upper-

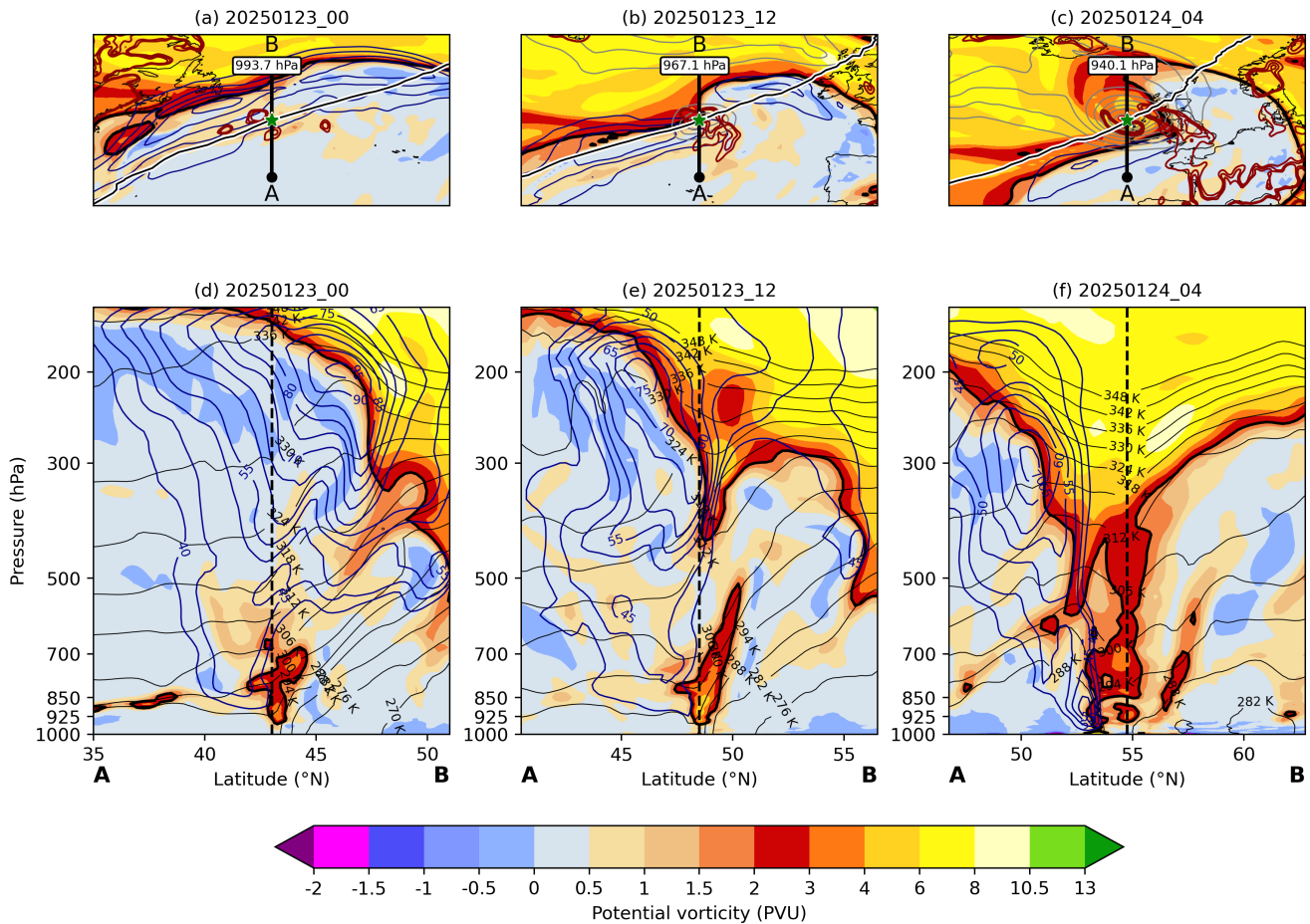


Figure 5. PV evolution during the intensification stage of Storm Éowyn based on ERA5. **(a-c)** Isentropic PV on 310 K (shading, PVU, bold black contour for 2 PVU), wind speed on 250 hPa (blue contours for 60, 70, 80, 90, 100, 110 and 120 m s^{-1}), SLP (grey contours every 5 hPa from 940 to 985 hPa) and low-level PV vertically averaged from 700 to 875 hPa (dark red contours for 1.2, 1.5 and 2.0 PVU in **a**, 1.5, 2.0 and 2.5 PVU in **b**, 2.0, 3.0 and 4.0 PVU in **c**). Green star marks the cyclone centre, text indicates the SLP*, and the black line shows the cyclone track. **(d-f)** Meridional cross sections along the black lines from 'A' to 'B' shown in the upper panels, with PV (shading, PVU, bold black contour for 2 PVU), potential temperature (thin black contours, every 6 K), and horizontal wind speed (blue contours, every 5 m s^{-1} starting at 40 m s^{-1}).

level jet, with a pronounced low-level PV signature in and southwest of the cyclone core (Fig. 2b). At 04 UTC on 24 January, the cyclone reached its maximum intensity with a SLP*_{min} of 940.1 hPa while it was located close to the northwestern coast of Ireland, just before making landfall (Fig. 2b, Fig. 5c). With this SLP*_{min}, Storm Éowyn is the ninth deepest cyclone on record among all cyclones impacting the British Isles since the 1959/60 season (Priestley and Stephenson, 2025).



Storm Éowyn crossed the British Isles on 24 January 2025 towards the North Sea (Fig. 2, Fig. 4, label 3). The weather station at Isle of Tiree (Scotland) recorded a minimum pressure of 941.9 hPa at 09 UTC (Meteostat, 2026) when the cyclone centre was at the west coast of Scotland (Fig. 2a). The high intensity of Storm Éowyn caused an expansive and powerful wind footprint over the eastern North Atlantic and the British Isles with maximum gusts just west of Ireland exceeding 55 m s^{-1} (Fig. 2a). At the time of maximum intensity (Fig. 2b), the cyclone had a clear bent-back frontal structure – a typical signature of mature Shapiro-Keyser cyclones (e.g., Browning, 2004), which are often associated with a cold conveyor belt or sting jet that can lead to very strong surface winds. After Storm Éowyn crossed the British Isles, the cyclone continued its path toward the coast of Norway. At about 70°N the cyclone curved to the west and eventually decayed at 02 UTC on 28 January 2025 southwest of Svalbard (Fig. 2a).

4 Sensitivity of cyclone characteristics in ICON simulations with varying horizontal resolution

Here, we investigate characteristics of Storm Éowyn in limited-area ICON simulations with varying horizontal grid spacings (see Tab. 1). For the intermediate horizontal resolution of 13 km, we additionally doubled and halved the number of vertical levels, but the sensitivity to these changes turned out to be weak and is only briefly discussed in Appendix A. All simulations were initialised at 12 UTC on 22 January 2025, which is approximately when the cyclone formed over the western North Atlantic (Fig. 2a).

4.1 Evolution of cyclone intensity

Although cyclone intensity can be evaluated through multiple dynamic and impact-oriented metrics, this analysis focuses primarily on SLP (with the impact of regridding to a common resolution alongside relative vorticity analyses detailed in Appendix B). Figure 6a shows the temporal evolution of SLP* along the track of Storm Éowyn for the five ICON experiments with varying horizontal resolution, ERA5, the IFS analysis, and the IFS ensemble forecast. There is a good agreement in SLP* along the track between ERA5 and the IFS analysis, despite differences in their spatial resolution, underlying model versions, and available output frequency. Regardless of horizontal resolution, the ICON simulations consistently underestimate the cyclone's peak intensity, with the underestimation of $\text{SLP}_{\min}^*$ ranging from 2.0 to 4.8 hPa compared to ERA5. During the main deepening phase, the SLP* evolution in ICON aligns well with the IFS ensemble. However, at maximum intensity only the high-resolution 3 km and 7 km simulations remain within the ensemble standard deviation. Later, the SLP* evolution in the ICON simulations falls outside the ensemble spread, with the 7 km run being closest to the ensemble and analyses. (Although this is not the focus of this study, it is remarkable to note how closely the ensemble mean captured the SLP* evolution of this explosively deepening cyclone with a relatively small spread indicating high confidence.)

While all ICON experiments show qualitatively good agreement in the temporal evolution of SLP*, increasing the model resolution tends to yield cyclone intensities closer to ERA5 (Fig. 6a). However, cyclone intensity does not increase monotonically with higher resolution: the 13 km experiment simulates a weaker cyclone than the coarser 20 km experiment, while the 7 km experiment simulates a stronger cyclone than the finer 3 km simulation. Although these results apply only to a single

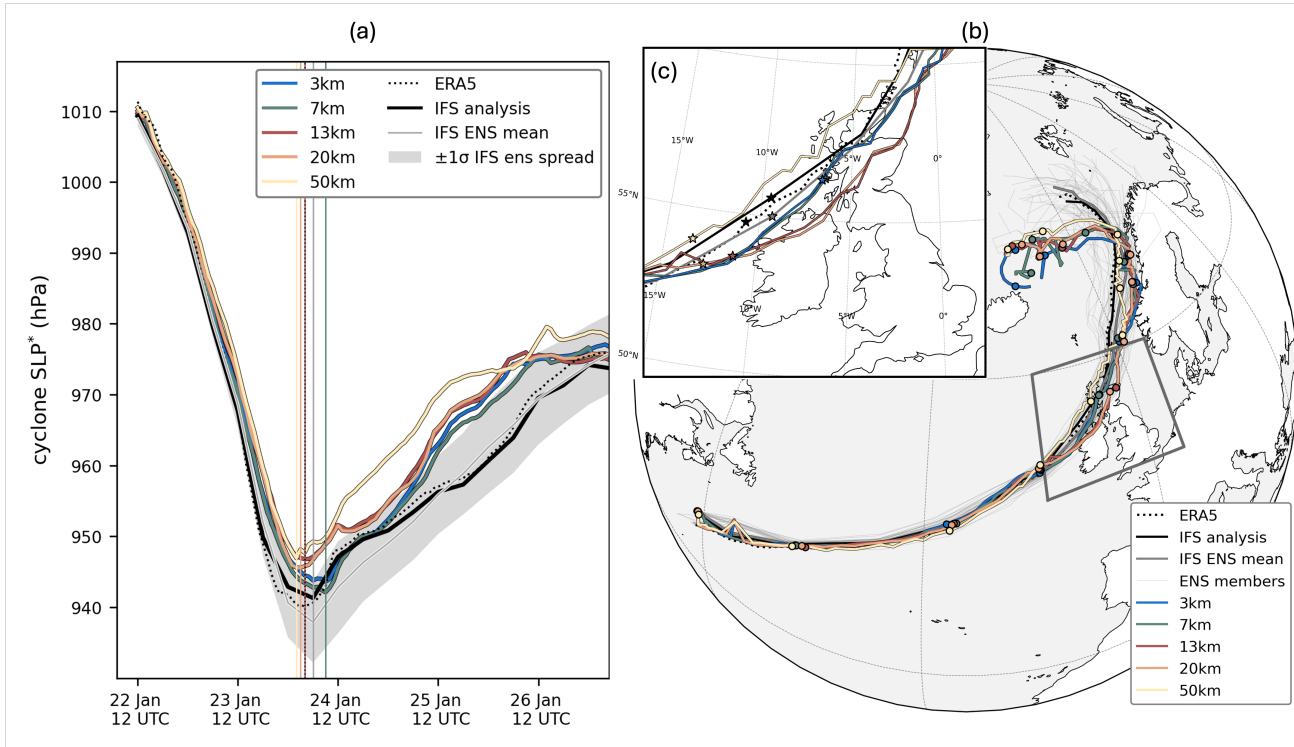


Figure 6. (a) Evolution of SLP* (in hPa) along the life cycle of Storm Éowyn based on ERA5 (black dotted, the same as in Fig. 4), IFS analysis (black solid; only 6-h values), five ICON simulations with different resolutions (coloured lines), and IFS ensemble forecasts (gray shading indicating $\pm$ one standard deviation and grey solid line for the ensemble mean). ICON simulations and IFS ensemble start at 12 UTC on 22 January 2025. Vertical lines show when the cyclone reaches its SLP*_{min}. (b) Tracks of the cyclone as identified from the different datasets. Dots show 12-h positions, starting at 12 UTC on 22 January 2025. (c) Zoom into the British Isles region (grey box in (b)). Stars mark the position of each cyclone along its track at the time it reaches its SLP*_{min}.

cyclone and initialisation time, they align with the general tendency for higher-resolution simulations to better capture the intensity of deep cyclones (e.g., Priestley and Catto, 2022). However, this relationship is not entirely robust (Priestley and Catto, 2022); for instance, 80 km simulations of cyclones in an idealized baroclinic channel yielded lower SLP*_{min} than their 2.5 km counterparts (Chen et al., 2024). For our set of experiments it is worth considering how convection is handled in the different simulations. The 13 km run is within the convective gray-zone, where the grid spacing is insufficient to fully resolve (deep) convection yet high enough to partially resolve it (e.g., McTaggart-Cowan et al., 2019). But we still also parameterise convection in this simulation. This might explain why the cyclone is better represented at 20 km, where convection must be fully parameterised. The 7 km and 3 km experiments, both with explicit convection only, match the SLP* evolution better than the coarser simulations after 00 UTC on 24 January, indicating a potential benefit of km-scale resolution simulations that no longer rely on a parameterisation of convection, consistent with previous findings (e.g., Field et al., 2017; Andrade Cardoso et al., 2026).



4.2 Cyclone track representation

250 Across all ICON resolutions, the simulated tracks of Storm Éowyn are overall similar to the tracks in ERA5, the IFS analysis, and the IFS ensemble mean (Fig. 6b). Short-term track jumps are evident after cyclogenesis in most ICON simulations, occurring in a region with a relatively flat SLP field. The 50 IFS ensemble forecasts help explain this behaviour, as they split into two distinct track branches during this stage. In the subsequent deepening stage until 24 January 2025, the simulated tracks match the (re)analysis-based tracks closely and exhibit nearly identical cyclone propagation speeds.

255 Starting 24 January, the simulated tracks increasingly diverge, showing marked differences as the cyclone approaches and crosses the British Isles (Fig. 6c). The tracks based on ERA5 and the IFS analysis pass north of Ireland, and the cyclone centre makes landfall on the west coast of Scotland. The coarse 50 km simulation yields a scenario where the cyclone is further north and only touches the northwestern tip of Scotland. Conversely, the 13 km and 20 km simulations produce highly similar tracks, both shifted southward relative to ERA5 and the IFS such that the centre directly strikes northern Ireland. The 3 km and 7 km
 260 simulations show a track between the ones in the intermediate and coarse simulations and therefore closest to the track in the (re)analysis. Readers interested in a deeper analysis of the differences in cyclone track across horizontal resolutions, as well as discrepancies in the timing of SLP_{min}^* (Fig. 6a), are referred to Appendix C. Importantly, all ICON tracks are within the envelope of the 50 IFS ensemble members, demonstrating that the resolution differences stay within the bounds of the IFS ensemble spread.

265 During the decay phase along the Norwegian coast, discrepancies between the tracks in the ICON experiments and the reference datasets become pronounced and larger than the variations among the ICON simulations (Fig. 6b). The ICON tracks remain closer to coast than the reference tracks (Fig. 6c), which co-occurs with a severe underestimation of SLP_{min}^* with deviations reaching up to 15 hPa (Fig. 6a). In the final decay stage (26–28 January 2025), the cyclone in the ICON simulations undergoes a more pronounced left-turn toward Iceland compared to ERA5 and the IFS analysis (Fig. 6b). Although the IFS
 270 ensemble mean follows the reference tracks, a minority of ensemble members also show this sharp turn, which indicates that in this phase, ICON still simulates physically plausible scenarios that are within the IFS ensemble spread.

Overall, these results show strong agreement among the ICON simulations during the initial intensification phase, with relatively small differences in deepening rate and exact track position. As the cyclone evolves further, higher horizontal resolution becomes crucial for capturing the landfall location.

275 4.3 Representation of cyclone structure and wind footprint

We now explore how the horizontal resolution of the simulation affects the structure of the high-impact cyclone and the associated impacts near the surface, with a focus on low-level wind speed (see Figs. S1-S4 in the Supplementary Material for wind fields at different levels and for precipitation). Figure 7k-o shows the footprint of the cyclone based on maximum 850 hPa wind speed and reveals that both the magnitude and spatial extent of high wind speeds are resolution-dependent.
 280 The area of strongest winds west of Ireland, as seen in ERA5 (Fig. 2a), is well captured at horizontal resolutions from 3 to 20 km; however, in the 50 km simulation, this region of high winds is largely absent. In addition, while the 13 and 20 km

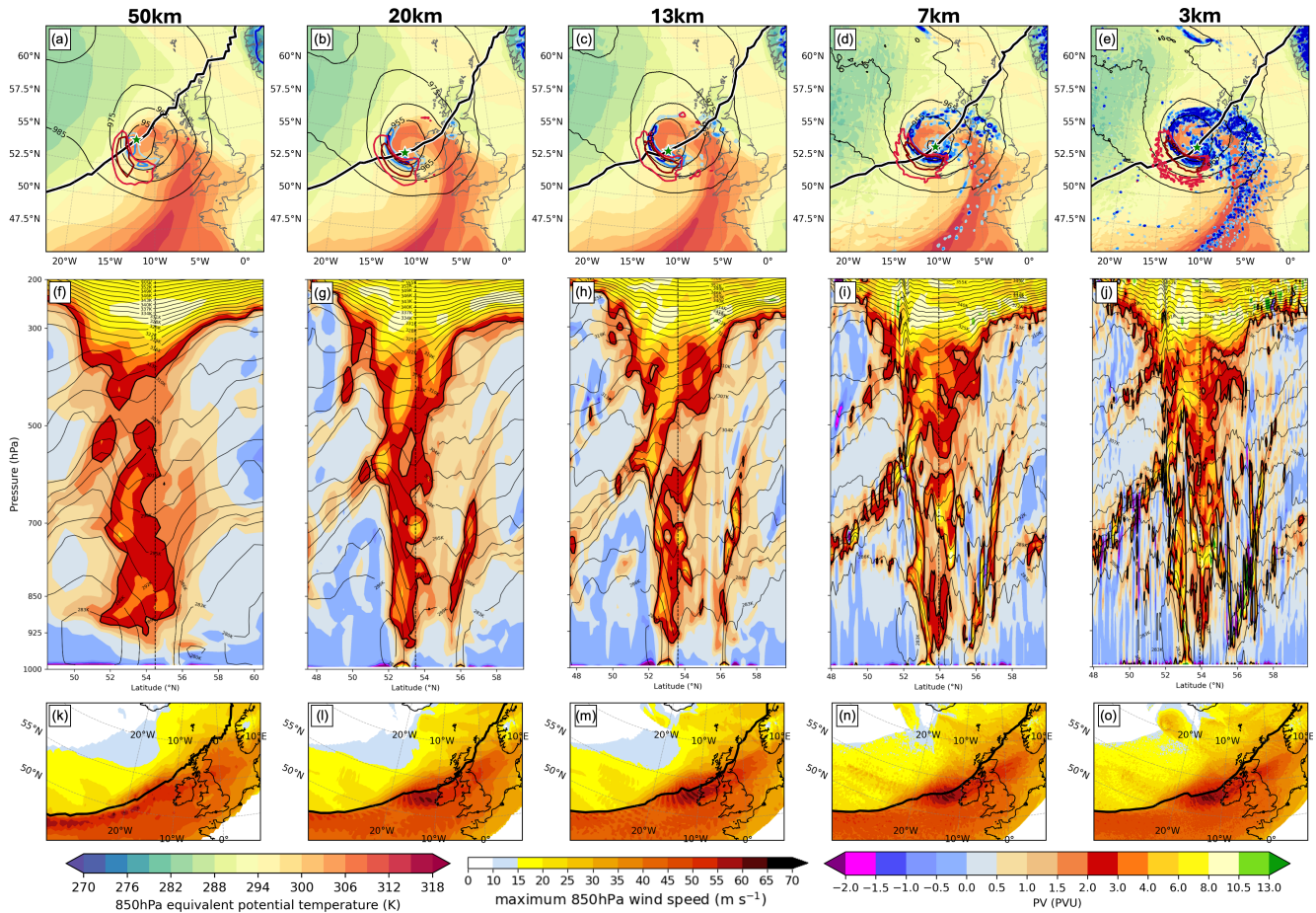


Figure 7. (a-e) 850 hPa equivalent potential temperature (shading, in K), SLP (black contours, 945-985 hPa in steps of 10 hPa), cyclone track (thick black line) and position of cyclone (green star), wind speed at 925 hPa (red: 25 m s^{-1} ; dark red: 30 m s^{-1}), and low-level PV (700-900 hPa mean; light blue: 2 PVU, mid-blue: 2.5 PVU, dark blue: 3 PVU). These fields are shown for ICON simulations with differing horizontal resolutions at 04 UTC on 24 January. (f-j) Vertical sections from south to north across the cyclone centre at 04 UTC on 24 January (see star in upper row) of PV (shading, in PVU) and potential temperature (every 3 K). (k-o) Footprint of 850 hPa wind speed maximum (shading, m s^{-1}) during the passage of Storm Éowyn (using a 1000 km radius around cyclone centre to attribute wind speeds to the cyclone). The black line marks the cyclone track.

simulations exhibit narrow bands of high wind speeds, the 3 and 7 km simulations show smoother patches of high wind speeds. As resolution increases, the wind speeds over Ireland increase to over 50 m s^{-1} with an area of occasionally over 60 m s^{-1} west of Ireland (Fig. 7l-o). In a cyclone-centred perspective (Fig. 7a-e), the wind maxima southwest of the cyclone centre are comparable in strength at 04 UTC on 24 January. With increasing resolution, however, the maxima shift eastward and become increasingly wrapped around the centre of the cyclone. This structural tightening is accompanied by a slightly sharper

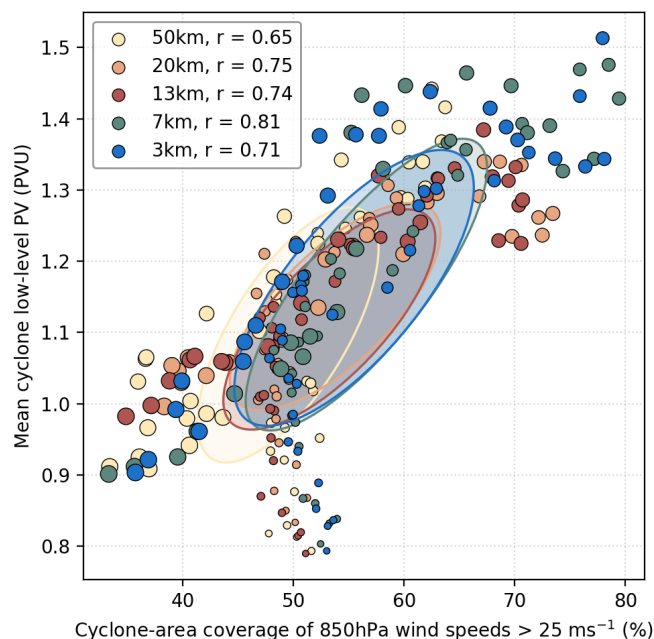


Figure 8. Relationship between mean low-level PV (700-900 hPa, averaged within 3°-radius around cyclone centre) and the cyclone-area coverage of 850 hPa wind speed exceeding a threshold of 25 m s^{-1} (cyclone area defined by a radius of 5°), shown for five simulations with different horizontal resolutions from 00 UTC on 23 January to 00 UTC on 25 January (one dot every hour). The size of the dots is scaled by time. The Spearman correlation is indicated in the figure legend. Shaded ellipses denote the 1σ confidence interval of the data distribution for each simulation.

low-level temperature gradient and enhanced wind speeds, particularly west of Ireland, highlighting how higher horizontal resolution refines the cyclones' wind footprint.

Beyond wind footprints, the mesoscale structure of the cyclone is sensitive to horizontal model resolution, particularly when
 290 looking at PV. All simulations successfully capture the characteristic PV tower at the time of the cyclone's peak intensity (Fig. 7, middle row). However, as expected, the PV towers in the high-resolution runs reveal more small-scale structures, extending up to the tropopause level with locally much higher positive and negative PV values (Fig. 7i, j) compared to the coarser simulations (in particular Fig. 7f). This is a well-known characteristic of km-scale simulations (e.g., Oertel et al., 2020). Additionally, the bottom-up formation of the PV tower is more evident in higher resolution simulations (Fig. C1).
 295 Horizontal maps also show clear differences in the magnitude of low-level PV between the simulations (Fig. 7, top row). The area with low-level PV exceeding 2 PVU increases significantly with higher resolution. Especially the 3 km simulation exhibits high low-level PV values in the core of the cyclone and along the fronts (Fig. 7e). Since these high low-level PV values are produced by diabatic processes, these differences reflect how the detailed cyclone structure depends on the representation of these processes at different resolutions.



300 To address how differences in mesoscale cyclone structure (especially lower-level PV) influence near-surface winds, we quantify the relationship between core PV (700–900 hPa) and the area of strong 850-hPa winds ($> 25 \text{ m s}^{-1}$) across horizontal resolutions. Figure 8 shows hourly evaluations from 00 UTC 23 January to 00 UTC 25 January. Independent of resolution, there is a significant positive correlation, indicating that higher low-level PV corresponds to a larger area of strong cyclone-related winds. Overall, higher resolution yields stronger correlations (0.65 for 50 km vs. 0.71 for 3 km; Fig. 8), though this behaviour is
 305 not monotonic. This increase in correlation with resolution highlights that higher horizontal resolution fundamentally improves the model's ability to simulate how diabatically produced low-level PV leads to high near-surface winds.

Notably, during the early deepening phase, scatter points deviate from this linear behaviour, displaying relatively large areas of strong winds despite relatively weak low-level PV (small dots in Fig. 8). This behaviour indicates that near-surface winds during the cyclone's initial development are likely also influenced by other dynamical processes—such as upper-level PV
 310 forcing or surface potential temperature anomalies.

5 The role of LH for Storm Éowyn

We now change subject and systematically evaluate the role of LH in the intensification of Storm Éowyn, using a series of sensitivity experiments that were conducted by scaling the model's LH constant from 0 % to 125 % (Sect. 2.3). All simulations were performed at a resolution of 13 km and those discussed in the next subsection were initialised at 00 UTC on 22 January
 315 2025. This timing precedes the initialisations in Sect. 4 by 12 h, thereby covering the entire cyclone deepening.

5.1 Relationship between LH and cyclone intensity

We first discuss the influence of modified LH on the evolution of SLP*. Even with LH completely suppressed ($\alpha = 0.0$), Storm Éowyn still develops through dry baroclinic processes but intensifies considerably less (Fig. 9), leading to a 18.7 hPa higher SLP*_{min} value than in the control simulation. This corresponds to a relative contribution of LH to the total cyclone deepening in
 320 the control of 27 % and indicates that, while diabatic processes significantly enhance the intensity of the cyclone, dry baroclinic instability is the primary driver of the deepening of Storm Éowyn. Compared to the studies summarized in Table 2 of Wernli and Gray (2024), this diabatic deepening contribution is rather modest. The deepening of the cyclone in the other experiments shows a monotonic behaviour with SLP*_{min} decreasing with increased α (Fig. 9). However, this behaviour is asymmetric and not perfectly linear. Halving LH ($\alpha = 0.5$) leads to a modest intensity deficit of 5.6 hPa, compared to almost 19 hPa with $\alpha = 0$.
 325 And while a 50 % reduction in LH results in a 5.6 hPa cyclone weakening, a mere 25 % increase in LH ($\alpha = 1.25$) leads to an additional deepening of 6.8 hPa.

Reducing LH causes a northward track shift compared to the control simulation (Fig. 9). The extent of this displacement depends on α , where a stronger reduction in LH generally yields a more pronounced northward shift. But in the experiment with $\alpha = 1.25$, the track is also shifted slightly northward in comparison to the control.

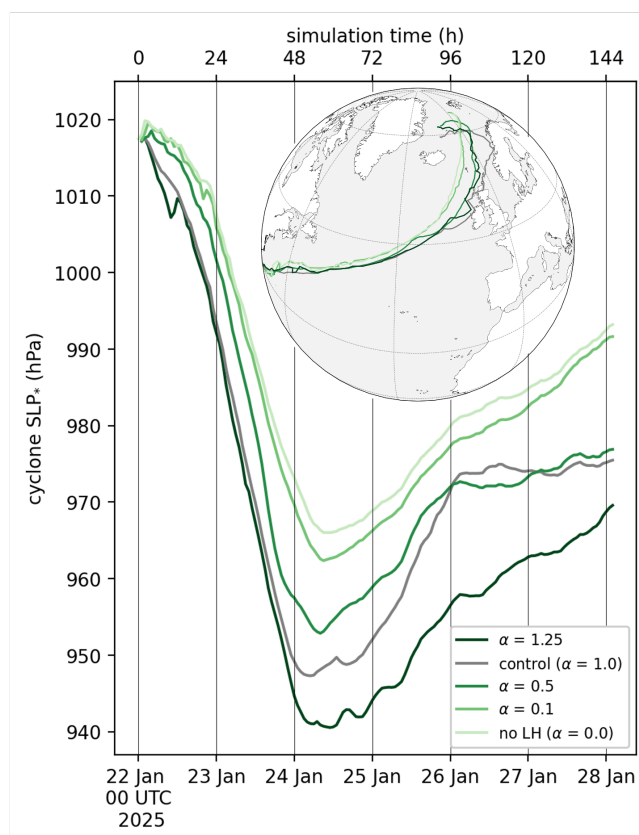


Figure 9. Evolution of the SLP* (in hPa) of Storm Éowyn and the associated tracks for the control simulation (grey) and the four LH experiments (coloured lines). All simulations are initialised at 00 UTC on 22 January 2025.

330 5.2 Sensitivity of LH contribution to time of initialisation

Previous studies evaluating the role of LH in cyclone development (e.g. Stoelinga, 1996; Odell et al., 2013; Büeler and Pfahl, 2017) relied on sensitivity experiments initialised at a single start time. However, it is conceivable that the LH contribution to cyclone deepening depends on initialisation, which we investigate here in detail, based on control and no LH experiments, again with 13 km grid spacing, started every 6 h from 00 UTC on 20 January to 12 UTC on 23 January. Note that the earliest
 335 initialisations at 00 UTC on 20 January are 2 d prior to the simulations discussed in the previous subsection.

A distinct cyclone develops in all experiments without LH (Fig. 10a), demonstrating again that LH acts as a modulator of intensity but is not a prerequisite for the cyclone's development. However, the earliest initialisation produces a substantially weaker cyclone in both the control and no LH simulations. Irrespective of initialisation time, the cyclones in the no LH experiments are systematically weaker than the ones in the corresponding control simulation. This emphasizes that LH enhances
 340 deepening throughout all phases of the cyclone's life cycle. Furthermore, in the control simulations, the cyclones systematically reach their maximum depth earlier than in the no LH simulations. This systematic delay indicates that LH does not only act as

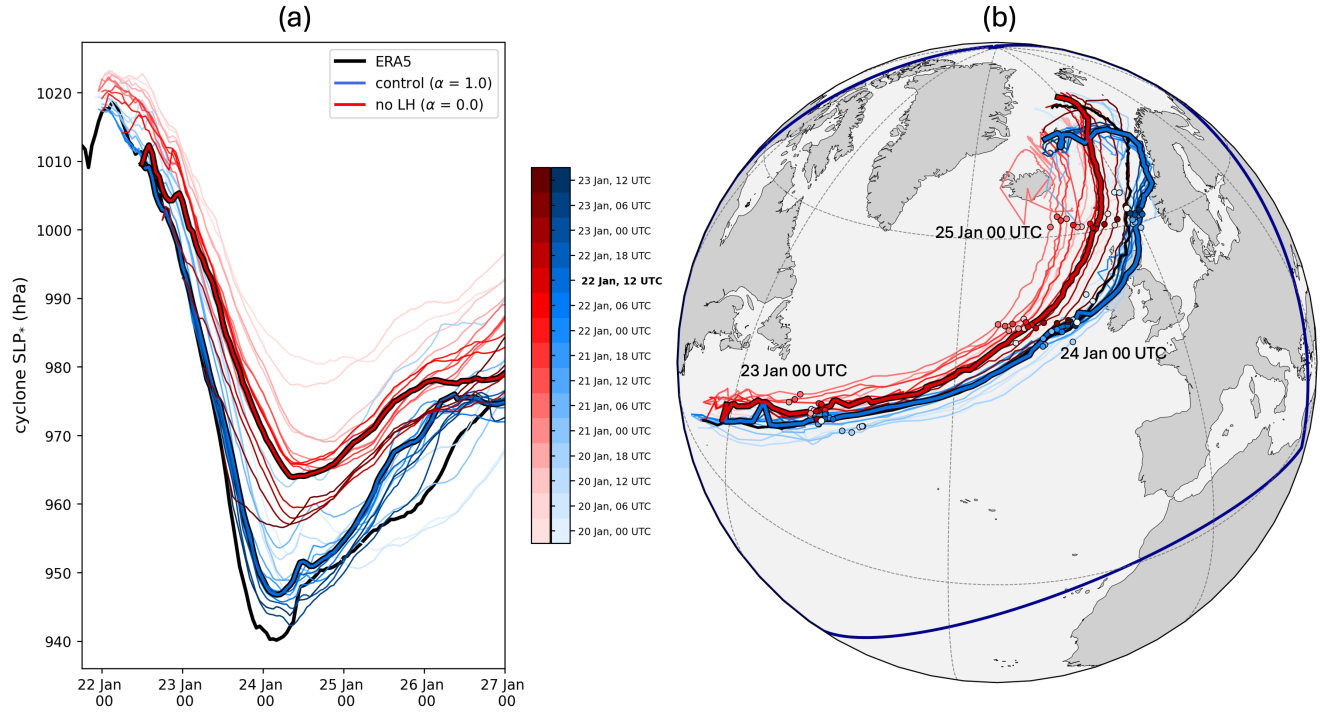


Figure 10. (a) Evolution of the SLP* (in hPa) along the life cycle of Storm Éowyn as represented in ERA5 (black), in ICON control simulations (blue lines) and in no LH experiments (red lines). Colour shading indicates time of initialisation. The bold red and blue lines correspond to the simulations started at 00 UTC on 22 January, which are used for a detailed analysis in Sect. 5.3 and 5.4. (b) Cyclone tracks from the ICON experiments (control and no LH) shown in (a). Markers indicate the position of the cyclone at 00 UTC on 23, 24, and 25 January.

a scaling factor for the cyclone’s core pressure but it also forces the cyclone to mature faster than a cyclone that deepens purely due to dry baroclinic instability.

In order to quantify the influence of LH on cyclone deepening, we determine the so-called diabatic deepening contribution (DDC; see Wernli and Gray, 2024), which is measured as the difference in SLP^*_{min} between the control and no LH experiments divided by the total deepening in the control since the start of the simulation. Adjusted for simulations with various initialisation times, we determine the DDC as

$$DDR = \left(\frac{SLP^*_{min, noLH} - SLP^*_{min, ctrl}}{SLP^*_{start} - SLP^*_{min, ctrl}} \right) \times 100\%,$$

with $SLP^*_{min, noLH}$ denoting the SLP^*_{min} of the cyclone in the no LH experiment, $SLP^*_{min, ctrl}$ the SLP^*_{min} of the cyclone in the control experiment, and SLP^*_{start} as the SLP^* of the cyclone at initialisation time (which is identical in both simulations).

Applied to all initialisation times between 20 and 23 January 2025, we find that the DDC ranges from 12 % to 53 % and is highly sensitive to initialisation time (Fig. 10a). The DDC follows a U-shaped pattern across initialisation times: starting high



(~40 %) for early initialisations, dropping to a minimum in the middle (~12 %), and peaking (~53 %) for late initialisations. The high DDC values at very early initialisations (before cyclogenesis) align with the largest absolute pressure drops (Δp up to 31 hPa). For the simulations initialised after genesis and during the first half of the deepening, the DDC decreases even though the absolute decreases in SLP* remain rather large (16–20 hPa). DDC increases again within the last initialisation, while the actual SLP* decrease falls below 15 hPa.

The non-monotonic change in DDC with initialisation time indicates how the physical importance of LH changes across the cyclone’s life cycle, playing a larger role during early cyclone formation and the final push to peak intensity. Consequently, early initialisations show how LH shaped the cyclone’s full evolution from genesis to maturity. Late initialisations, where past LH is already locked into the initial conditions, answer the narrower question of how much LH influences the final deepening.

Apart from changes in the intensity of the cyclone when modifying LH, there are marked changes in the propagation speed and especially the track, with clear sensitivities to the initialisation time (Fig. 10b). Specifically, the cyclone propagation is slower in the no LH experiments (see the fixed time markers in Fig. 10b), revealing that the cyclones in the no LH experiments consistently lag behind the ones in the control runs. This aligns well with the findings of Christ et al. (2026), who noted that ETCs driven by strong LH propagate faster than those primarily driven by dry dynamics. The ensemble of tracks in the no LH experiments is systematically north of the control ensemble and shows a larger spread, i.e., a stronger sensitivity to initialisation time. It appears that for this cyclone LH acts as a “stabilizer” for the cyclone’s path. Not surprisingly, the magnitude of the track deviations between control and no LH experiments scales with the length of the simulation. Considering track direction, cyclones in the no LH experiments consistently move to the northwest of their control counterparts.

Combining our results with the sensitivity to α demonstrates that the cyclone tracks are jointly governed by LH and initialisation time. While the reduction in cyclone intensity under reduced LH is well-established (e.g., Büeler and Pfahl, 2017), the track response presents a more complex picture. Idealized climate studies generally suggest that increased moisture promotes poleward deflection of ETCs (e.g., Coronel et al., 2015; Tamarin and Kaspi, 2016; Tamarin-Brodsky and Kaspi, 2017), implying that reducing LH should result in a southward shift. Instead, we observe a distinct northward displacement that intensifies the more LH is reduced, which however aligns with single-case ETC studies (Odell et al., 2013; Büeler and Pfahl, 2017). In addition, our multi-initialisation approach resolves some discrepancies in the amplitude of the track displacement among prior case studies. By evaluating the cyclone across multiple initialisation times (Fig. 10b), we demonstrate that track deviations accumulate non-linearly over time and depend on the initialisation stage. This temporal dependency may explain why shorter simulations, such as the 30-hour simulation in Büeler and Pfahl (2017), observed only a modest path shift (~1.5°), whereas longer integrations, like the 4.5-day simulation in Odell et al. (2013), produced larger displacements (~2–3°). Thus, considering initialisation and simulation duration provides valuable context for comparing case-study results.

5.3 Understanding the cyclone track shift in the experiments without LH

Although multiple studies have documented that suppressing LH modifies the track of ETCs, they typically treated track modifications as a by-product without providing explanations (e.g. Odell et al., 2013; Büeler and Pfahl, 2017). Here, we aim to provide a mechanistic explanation by investigating how the full suppression of LH changes the large-scale flow pattern

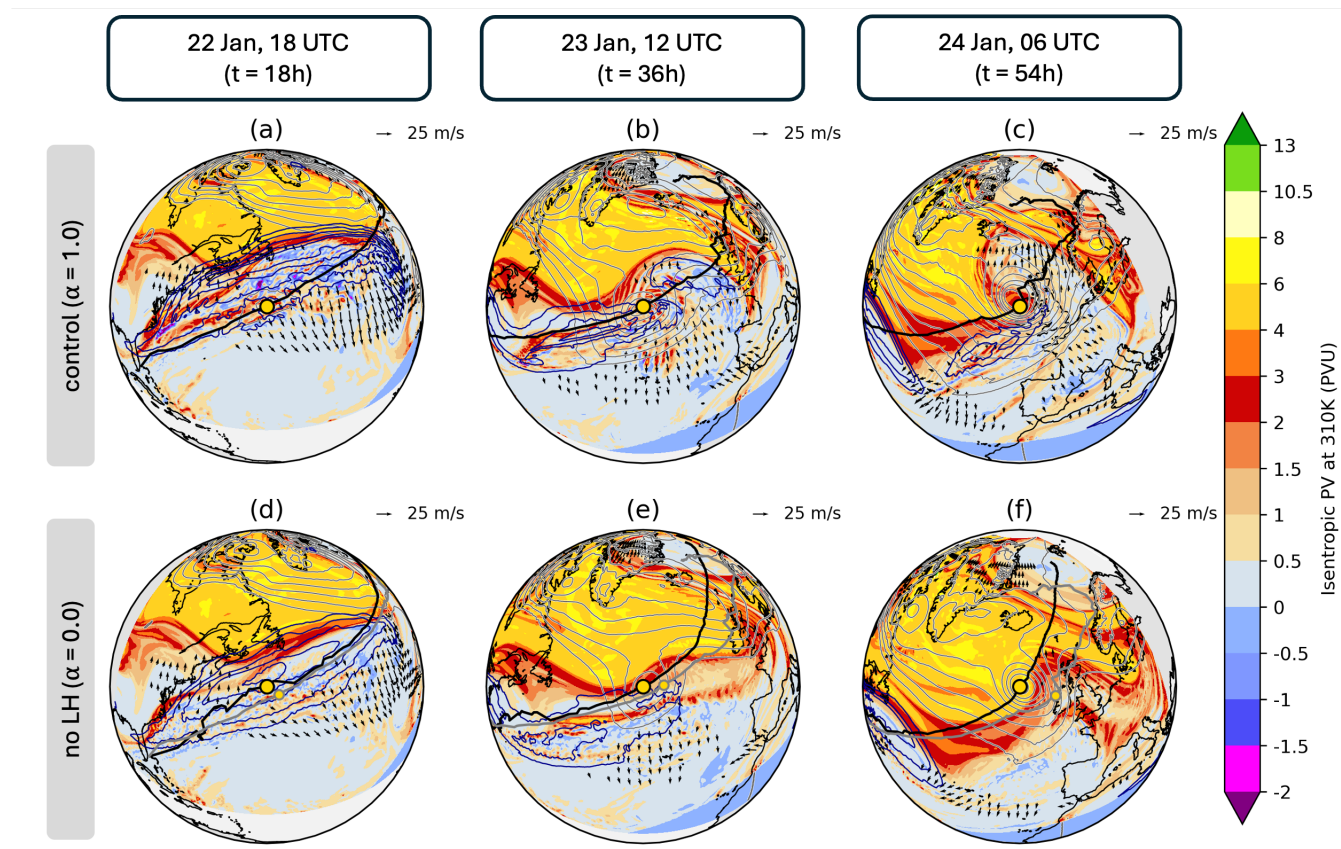


Figure 11. Evolution of upper-level PV at 310 K (shading, PVU), 250 hPa wind speed (blue contours, 60-100 m s⁻¹ in steps of 10 m s⁻¹), vectors of divergent winds at 250 hPa (black arrows, only shown where wind speed exceeds 10 m s⁻¹), and SLP (grey contours, 940 to 1010 hPa in steps of 5 hPa) for (a-c) the control simulation and (d-f) the no LH experiment. Both simulations were initialised at 00 UTC on 22 January with a horizontal grid spacing of 13 km. Fields are shown at (a, d) 18 UTC on 22 January, (b, e) 12 UTC on 23 January, and (c, f) 06 UTC on 24 January. Black lines denote cyclone tracks, and the gold marker the instantaneous cyclone centre. In the lower row, the cyclone track from the control simulation is overlaid in grey to facilitate direct comparison with the no LH track (black).

compared to the control simulation, and how these changes feed back on the cyclone's non-linear intensification. For this analysis, we select the two simulations initialised at 00 UTC on 22 January (thick lines in Fig. 10a).

Figure 11 shows synoptic maps at selected times during the intensification of the cyclone in the control and no LH simulations (additional time steps are shown in the Supplementary Material, Figs. S5-S12). After 18 h into the simulation, the large-scale circulation is still very similar in the two experiments, though the cyclone in the no LH experiment already exhibits a slight northward shift (Fig. 11a, d). While an elongated upper-level jet extends across the North Atlantic in both simulations, it is notably more intense and extends further east in the control simulation. Furthermore, the position of the cyclone relative

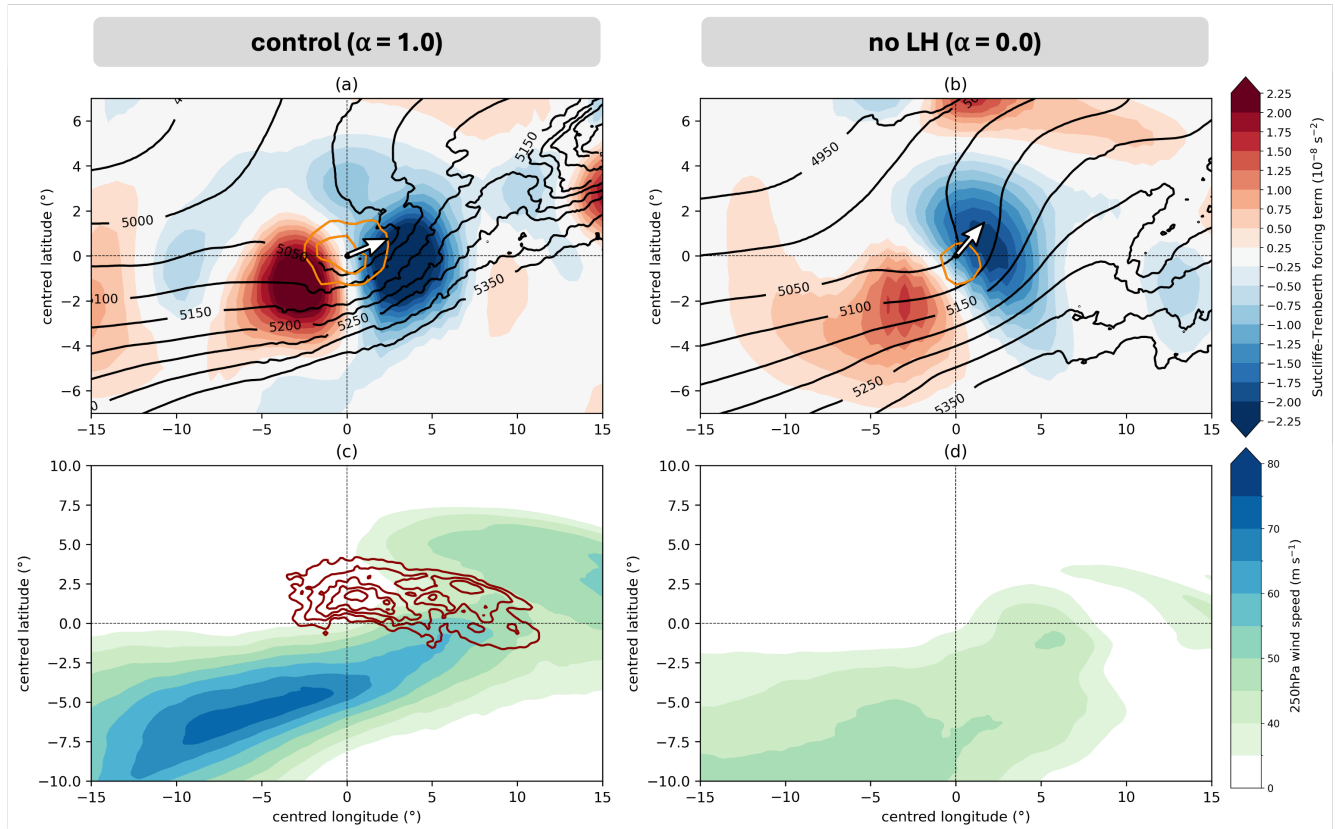


Figure 12. Cyclone-centred composites for the period from 12 UTC on 23 January to 12 UTC on 24 January. (a,b) Sutcliffe-Trenberth (ST) forcing term (shading, s^{-2}), mean 1000-500 hPa thermal wind at cyclone centre (thick white arrow, $m s^{-1}$), 500-1000 hPa thickness (black contours, gpm), and geostrophic absolute vorticity at 500 hPa (orange contours for 4 and $5 \cdot 10^{-4} s^{-1}$). (c,d) 250 hPa wind speed (shading, $m s^{-1}$) and 500-850 hPa layer-mean LH (dark red contours for $[3,4,5,6,7] \cdot 10^{-4} K s^{-1}$). The ST forcing term was calculated on a resolution of 1° , and thickness and LH fields were smoothed spatially with a Gaussian filter.

to the jet diverges early: in the no LH experiment the cyclone centre is already below the jet core, whereas the control cyclone
 395 remains south of the jet.

At 12 UTC on 23 January, 18 h later, the no-LH cyclone is further west compared to the control cyclone, pointing to a reduced
 propagation speed (Fig. 11b, e). In addition, notable differences emerge in the large-scale flow. In the control simulation,
 pronounced diabatic ridge-building takes place downstream of the cyclone that co-occurs with upper-level divergent outflow,
 which initiates a secondary jet maximum along the northern flank of the ridge. In contrast, the upper-level flow downstream of
 400 the cyclone in the no LH experiment remains largely zonal.

These differences in the large-scale flow become even more pronounced by 06 UTC on 24 January, when the control simula-
 tion features a highly amplified downstream ridge accompanied by divergent outflow, with the cyclone maintaining a favourable
 position north-east of a jet streak. In contrast, the no LH simulation reveals a significantly weaker cyclone that lacks the sup-



port of vortex stretching in the left upper-level jet exit. Moreover, the downstream ridge is much less pronounced such that the
 405 cyclone remains exposed to a weak flow from the south associated with the downstream flank of the broad upper-level trough,
 resulting in a stronger northward movement of the cyclone.

To further understand the slower and more northward cyclone propagation in the no LH experiment, we apply the Sutcliffe-
 Trenberth (ST) framework (Sutcliffe, 1947; Trenberth, 1978). This framework states that a cyclone propagates toward the
 region of maximum cyclonic geostrophic vorticity advection by the thermal wind vector. By calculating the ST-forcing, given
 410 by $2(\mathbf{V}_T \cdot \nabla \eta_g)$ (with the 500-1000 hPa thermal wind $\mathbf{V}_T$ and the absolute geostrophic vorticity at 500 hPa η_g), areas of
 negative ST-forcing highlight where the cyclone is likely to move next. Figure 12 presents cyclone-centred composites for the
 time period between the start of the track deviation and the maximum intensity of the cyclone (12 UTC on 23 January to 12
 UTC on 24 January). In the control simulation, intense LH occurs north and north-east of the cyclone centre, most likely in
 the region of the warm conveyor belt (Fig. 12c). LH increases the 1000-500 hPa thickness close to the cyclone core, and, as a
 415 result, the horizontal gradient in thickness (Fig. 12a). The tight thickness contours south of the cyclone centre indicate strong
 lower-to-middle tropospheric thermal wind shear, which contributes to the high-magnitude upper-level jet observed at 250 hPa
 in that region (Fig. 12a, c). The strong eastward thermal wind advects cyclonic vorticity close to the cyclone centre (orange
 contours) to the east, which results in strongly negative ST forcing directly east of the cyclone centre. The cyclone follows this
 forcing and propagates to the east. In contrast, the ST-forcing is weaker in the no LH experiment. As by experiment design, LH
 420 is absent (no LH contours in Fig. 12d), and the horizontal thickness gradient south of the cyclone is much weaker. This leads to
 a much weaker upper-level jet, and the thermal wind vector at the cyclone centre is rotated compared to the control simulation
 and points noticeably more to the north (Fig. 12b). This modification of the thermal wind rotates the ST-forcing dipole, such
 that the zone of negative ST-forcing changes from directly east of the cyclone centre to the northeast. Consequently, the cyclone
 propagates earlier to the north and, due to the weaker ST-forcing, with reduced speed.

425 Contextualizing our findings within the existing body of literature, the reduced propagation speed of the no-LH cyclone
 aligns with previous studies highlighting the role of moist processes in driving rapid eastward cyclone motion (e.g., Davis
 et al., 1993; Boettcher and Wernli, 2013; Coronel et al., 2015). LH generates a low-level cyclonic circulation tendency that
 promotes faster eastward displacement and overcomes the westward tendency exerted by the upper-level anticyclone (Coronel
 et al., 2015). Despite the lower propagation speed, our no-LH cyclone crosses the jet earlier than the control. This timing
 430 contrasts with the idealized dry-versus-moist experiments of Coronel et al. (2015), where dry cyclones crossed the jet later. We
 suspect this timing is reversed because the jet streak in our real-case control simulation extends further northeast, placing the
 jet farther away from the cyclone.

5.4 Still a high-impact cyclone over the British Isles?

Lastly, by comparing the control run with the no-LH experiments initialised at 00 UTC on 22 January 2025, we assess how fully
 435 suppressing LH impacts the mesoscale structure of the cyclone and the associated surface weather. Specifically, we examine
 near-surface wind speed differences both relative to the cyclone centre and across the British Isles.

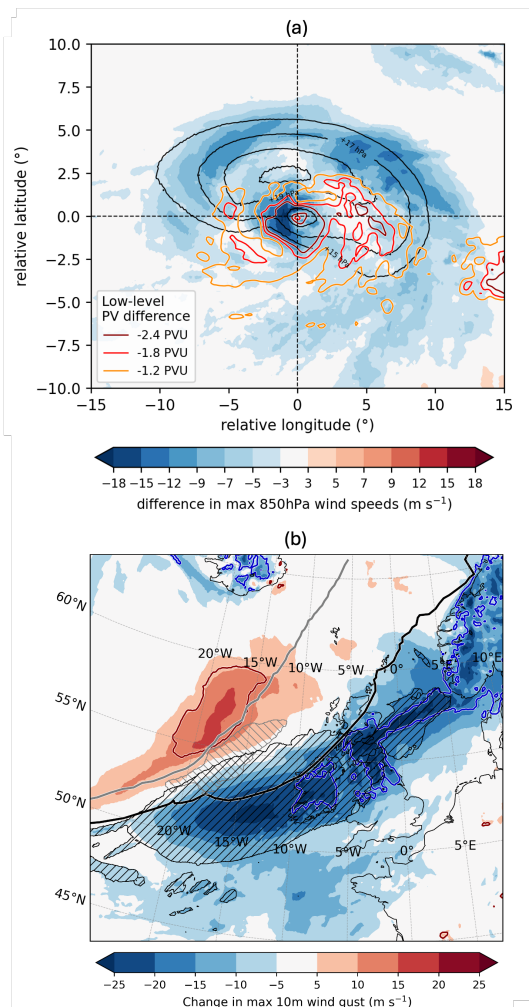


Figure 13. (a) Difference in cyclone-centred composite (12 UTC on 23 January until 18 UTC on 24 January) of maximum 850 hPa wind speeds (shading, m s^{-1}), SLP (black contours, hPa), and low-level PV (700-900 hPa, PVU; spatially smoothed with Gaussian filter with $\sigma = 1$) between the no LH experiment ($\alpha = 0.0$) and the control simulation ($\alpha = 1.0$). Note that the fields have been rotated prior to compositing such that the propagation direction of the cyclone is to the right. (b) Change in maximum 10 m wind gusts (shading, m s^{-1}), relative reduction/increase in maximum 10 m wind gusts of +/- 50 % (dark blue/red contour line, respectively), and the cyclone tracks for the cyclone in the two simulations (black: control, grey: no LH), for the time period 12 UTC on 22 January to 00 UTC on 26 January 00. Hatching indicates where the wind gusts exceed 40 m s^{-1} at least once (black: control, grey: no LH).

The reduction in cyclone intensity in the no LH experiment is accompanied by a much weaker low-level, positive PV anomaly around the cyclone centre and weaker low-level winds compared to the control simulation (Fig. 13a). This reduction in low-level PV is strongest near the cyclone centre, with differences exceeding 2.4 PVU. Consequently, this decreased PV directly co-occurs with a reduction in maximum 850 hPa wind speeds across the cyclone area, consistent with our earlier

finding of a strong correlation between the strength of low-level PV within a radius around the cyclone centre and the maximum wind speeds (Fig. 8). The most striking wind speed reduction exceeds 18 m s^{-1} and is located southwest of the cyclone centre (Fig. 13a)—a region typically associated with the highest surface wind speeds related to the cold conveyor belt and sting jet. Thus, suppressing LH fundamentally disrupts the production of low-level PV and leads to a substantial weakening of both the cyclone’s core structure and its most severe low-level winds.

To understand how this weakened core structure impacts the swath of high near-surface wind speed associated with the cyclone, we consider the footprint of maximum 10 m wind gusts during the passage of the cyclone. The experiment without LH shows two main differences: first, the cyclone-related wind gusts are weaker (Fig. 13a), and, secondly, the northwestern shift in the cyclone track additionally deflects the region of highest wind gusts (Fig. 13b). As a result, the zone of highest wind gusts linked to the cyclone in the no LH experiment misses the British Isles and shifts instead into the largely uninhabited open waters between the UK and Iceland, where peak wind gusts consequently increase by over 50 %. The combination of a less intense cyclone and a shifted cyclone track leads to a strong decrease in wind gusts over populated regions, including Norway, northwestern France, and the British Isles—with peak wind gusts dropping by over 50 % across most of Ireland, northern England, and southern Scotland, which is precisely the region where the control simulation produced maximum 10 m wind gusts exceeding 40 m s^{-1} (stippling in Fig. 13b), and locally even 50 m s^{-1} .

In summary, we answer this subsection’s leading question with a clear ‘no’: the offshore track shift of the no-LH cyclone prevents high winds from impacting the British Isles, reducing hazards over land linked to this cyclone below operational warning thresholds.

6 Predictability of Storm Éowyn and the sensitivity of cyclone representation to initialisation time

While we explored the sensitivity to initialisation time before (Sect. 5.2), we here focus on the variations in cyclone intensity and surface hazards (10 m wind gusts) as a function of forecast lead time to quantify predictability aspects of this high-impact cyclone. For that purpose, we consider ICON control simulations ($\alpha = 1$), initialised every 6 h and the 50-member IFS ensemble forecasts (initialised every 12 h; see Sect. 2.5). To enable a reasonable comparison, we first evaluate ICON simulations with a horizontal resolution of 13 km, which matches the effective resolution of the IFS ensemble forecasts. In a second step, we then explore the complex, non-linear response in cyclone intensity that arises when the initialisation time and the horizontal grid spacing are varied simultaneously.

6.1 Predictability of Storm Éowyn in IFS ensembles

Following the methodology of Hartmuth et al. (2026, their Sect. 2.3), we evaluate IFS ensemble forecasts from 12–23 January by checking each member for a cyclone track that matches the one of Storm Éowyn in ERA5. A match is defined as a cyclone position remaining within a 500 km radius of the ERA5 track for at least 18 h (i.e., at three consecutive time steps).

For ensemble forecasts initialised on 12–16 January 2025, the majority of ensemble members do not capture the occurrence of the cyclone west of the British Isles by 24 January (Fig. 14; grey bars). Investigating the minority of ensemble members

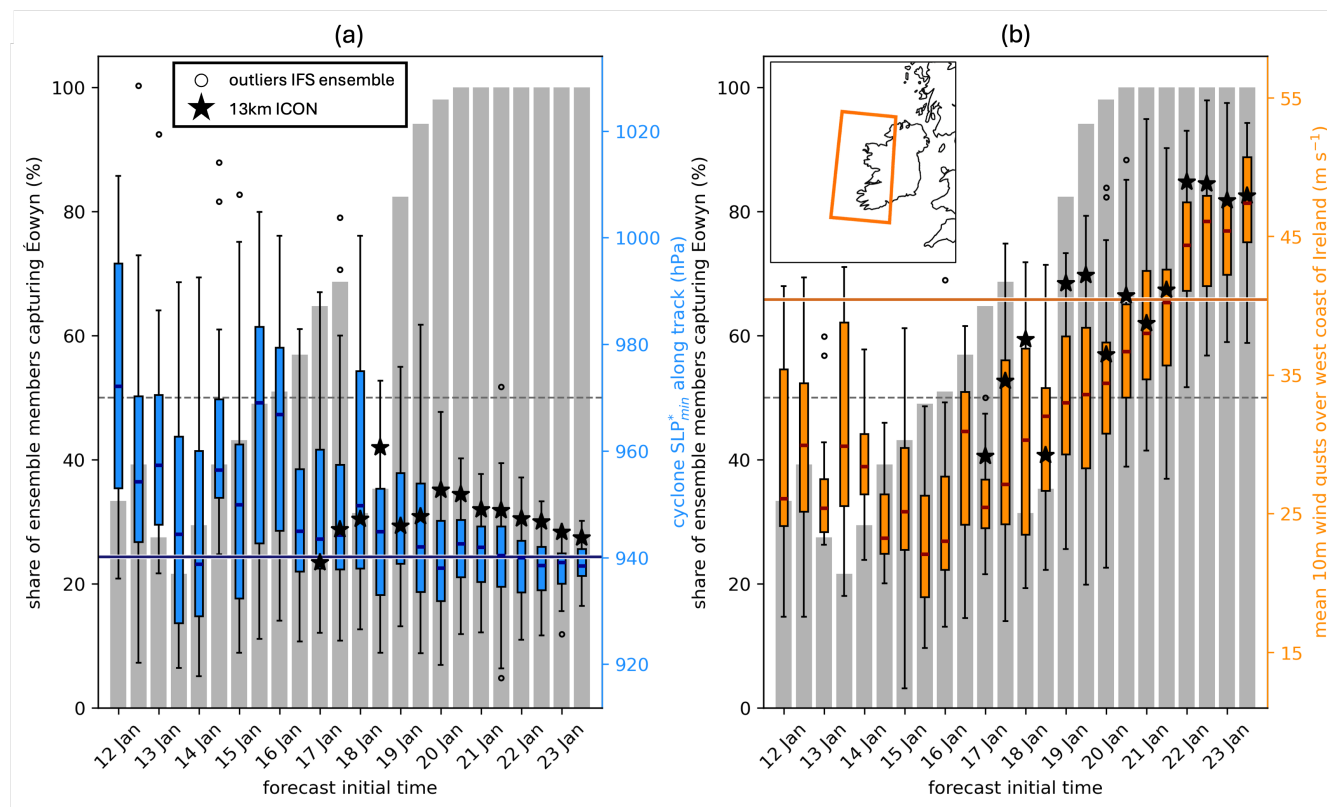


Figure 14. Predictability of Storm Éowyn in the 50-member global IFS ensemble and the 13 km limited-area ICON simulations. Grey bars (identical in both panels) represent the percentage of IFS ensemble members containing a cyclone track that matches with Storm Éowyn (left y-axis) as a function of initialisation time (every 12 h from 00 UTC on 12 January to 12 UTC on 23 January). The horizontal grey dashed lines indicate a value of 50 %. Blue box plots in (a) show the distribution of SLP_{min}^* (hPa), and orange box plots in (b) the 10 m maximum wind gust distribution ($m s^{-1}$) for 23–25 January 2025, area-averaged over western Ireland (indicated by the orange box in the inset of b). Right y-axes are valid for the respective box plots. Thick horizontal lines represent ERA5 values, and stars denote the 13 km ICON simulation values. Box plot medians are indicated by thick horizontal lines in a darker colour, and outliers are shown as black circles.

that feature a cyclone reveals a large spread in SLP_{min}^* , with medians fluctuating between 940 and 970 hPa (Fig. 14a, blue box plots) compared to the ~ 940 hPa in ERA5. For forecasts initialised between 16–17 January, the fraction of ensemble members with a cyclone that roughly matches Storm Éowyn increases to above 50 %. Note that these forecasts have been initialised 4–5 days prior to cyclogenesis over the western North Atlantic, agreeing well with the forecast horizon mentioned by ECMWF specifically for Storm Éowyn (Magnusson et al., 2025). At the same time, the median in SLP_{min}^* stabilizes with decreasing lead time and converges toward the ERA5 value.

Both ensemble initialisations on 18 January (00 and 12 UTC) struggle to capture the cyclone (Fig. 14, grey bars). Compared to the preceding seven initialisations (14–17 January), where a much higher proportion of members detected the cyclone, the



rate drops sharply to only 30–35 %. However, those members that do simulate the cyclone yield a median in SLP_{min}^* in close agreement with ERA5. This indicates that forecast uncertainty on 18 January was primarily driven by whether the cyclone would form, rather than its expected intensity.

For forecast initialisation times after 18 January, an increasing number of ensemble members captured the cyclone, reaching
 485 complete consensus from 12 UTC on 20 January onwards (Fig. 14a, grey bars). Coinciding with this ensemble confidence, the UK Met Office issued its first warnings on 20 January (Met Office Press Office, 2025). As consecutive initialisations persistently predicted a high-impact cyclone, the UK Met Office officially named the cyclone on 21 January, still one day prior to its formation far off the British Isles (Met Office Press Office, 2025). Between 21 and 23 January, the distribution of SLP_{min}^* narrowed further to an interquartile range of only a few hPa, reflecting high confidence in the occurrence of a high-intensity
 490 cyclone—corresponding to the “ideal behaviour” of an ensemble prediction system.

In terms of hazards, the IFS ensemble indicated early on the potential for severe weather west of and across the British Isles, based on the extreme forecast index (Magnusson et al., 2025). The orange box plots in Fig. 14b display the maximum 10 m wind gusts averaged over the west coast area of Ireland (8–12°W, 51–55.5°N; see inset in Fig. 14b) for the time period 23–25 January 2025, when Storm Éowyn hit the British Isles. Similar to the SLP_{min}^* , 10 m wind gusts exhibit substantial spread during
 495 early initialisation times before converging toward ERA5 values for later initialisations (Fig. 14b). The spread in wind gusts is large during early forecast initialisations with median gusts in the ensemble between 23 and 30 m s^{−1} until 16 January, which is much lower compared to the ERA5 value of 40 m s^{−1}. For the period with high forecast uncertainty (18 January), the spread in wind gusts across the ensembles is again high, indicating that although some ensemble members capture the cyclone and approximately its strength (Fig. 14a), the wind hazard for the the area west of the British Isles is more uncertain. With later
 500 initialisation times, the median wind gusts increase and even exceed the ERA5 value from 21 January on (Fig. 14b), peaking in nearly 50 m s^{−1} for the latest initialisation time at 12 UTC on 23 January. The stronger wind gusts in the ensembles might be related to differences in model formulation, in particular the way the wind gusts are parametrised, and model resolution. Interestingly, the stochastic perturbations of the parameterisations in the IFS ensemble led to a very low surface momentum flux in that period, which then led to a systematic overestimation in wind gusts (personal communication with Sarah-Jane
 505 Lock, ECMWF, April 2026).

Connecting the analyses in Fig. 14a and b, we find a strong, statistically significant negative correlation between the median 10 m wind gusts and the median SLP_{min}^* ($r = -0.70, p < 0.001$), indicating higher wind gusts west of the British Isles for more intense cyclones in the ensemble, and vice versa. However, while the spread in SLP_{min}^* narrows with later initialisation times, wind gust spread exhibits no such clear convergence. This suggests that while the cyclone intensity is more certain, the exact
 510 location of its path and therefore the corridor with the highest wind speeds is less certain.

6.2 Are limited-area ICON simulations of the cyclone captured by the IFS ensemble envelope?

Drawing back the attention to our ICON simulations, it is of value to see whether cyclone intensity and surface wind gusts simulated in ICON are within the range of the IFS ensemble forecasts. To address this, we plotted ICON simulation results



(13 km grid spacing) as star markers in Fig. 14. They represent the SLP_{min}^* along the cyclone track and maximum 10 m wind gusts over western Ireland, evaluated every 12 h between 00 UTC 17 January and 12 UTC 23 January.

For ICON simulations initialised between 17 and 23 January, SLP_{min}^* values all remain within 1.5 interquartile ranges of the ensemble's upper and lower whiskers and some fall inside the central interquartile range (Fig. 14a). Except for the initialisation at 00 UTC on 17 January, ICON underestimates SLP_{min}^* compared to both ERA5 and the ensemble median. Between 17 and 20 January, SLP_{min}^* exhibits significant variability from less than 940 hPa in the ICON simulation initialised at 00 UTC on 17 January to more than 960 hPa in the simulation initialised at 12 UTC on 18 January. In comparison to the other initialisations, the experiment in which the cyclone reaches a SLP_{min}^* of 960 hPa stands out: the cyclone track is heavily shifted to the south, such that the cyclone grazes the southern coastline of Ireland (Fig. D2). The deviation between the SLP_{min}^* in ICON and ERA5 decreases monotonically only from 00 UTC on 20 January onward, when SLP_{min}^* drops from 952 to 934 hPa between 20 and 23 January (Fig. 14a).

Considering wind gusts in ICON, Fig. 14b clearly shows comparatively high values in ICON compared to the IFS ensemble, although ICON values always remain within the ensemble spread. A discussion of possible reasons for this systematic behaviour is provided in Appendix D.

6.3 The initial time-resolution dependency for cyclone intensity

Building on our separate analyses of horizontal resolution (Sect. 4.1) and initialisation time (Sect. 5.1 and 6.2), this subsection evaluates how these two parameters jointly influence cyclone deepening and track deviation. Figure 15 displays the difference of SLP_{min}^* between ERA5 and ICON, as a function of horizontal resolution and initialisation time of the ICON simulations.

In agreement with Sect. 4.1, SLP_{min}^* is systematically underestimated relative to ERA5 across all initialisations from 00 UTC on 17 January to 12 UTC on 23 January, independent of the horizontal resolution (Fig. 15). This underestimation in cyclone intensity in ICON reaches up to +29 hPa and is strongly modulated by horizontal resolution. Across all initialisation times, the coarser configurations exhibit the largest mean SLP_{min}^* overestimation of ~ 15 hPa, which progressively decreases to ~ 11 hPa at 20 km and ~ 8 hPa at 13 km. This resolution-dependent bias points to the inability of coarser grids to fully resolve the steep pressure gradients.

There is a strong negative correlation between initialisation time (relative to 24 January) and deviations of SLP_{min}^* from ERA5, especially for coarser resolutions (Fig. 15). When evaluating the correlation between initialisation time and the deviation in SLP_{min}^* across model simulations, later initialisations yield substantially lower deviations with correlations of -0.6 and -0.54 for the 50 km and 20 km simulations, respectively. In contrast, the correlation is very low for the 13 km simulations (-0.08), indicating a more stable deviation across all initialisation times. This suggests that at coarser model resolutions, the cyclone must be present in the initial conditions in order for the model to simulate the cyclone with reasonable accuracy, while at 13 km resolution the cyclone deepening is captured appropriately even for initialisation times prior to cyclogenesis.

The 3 km runs consistently outperform all other configurations with a mean deviation in the SLP_{min}^* from ERA5 of ~ 5 hPa. This points to the critical role of explicitly resolving convective-scale processes to accurately simulate the rapid deepening of the cyclone. However, the 7 km configuration exhibits a non-monotonic behaviour by occasionally producing higher deviations

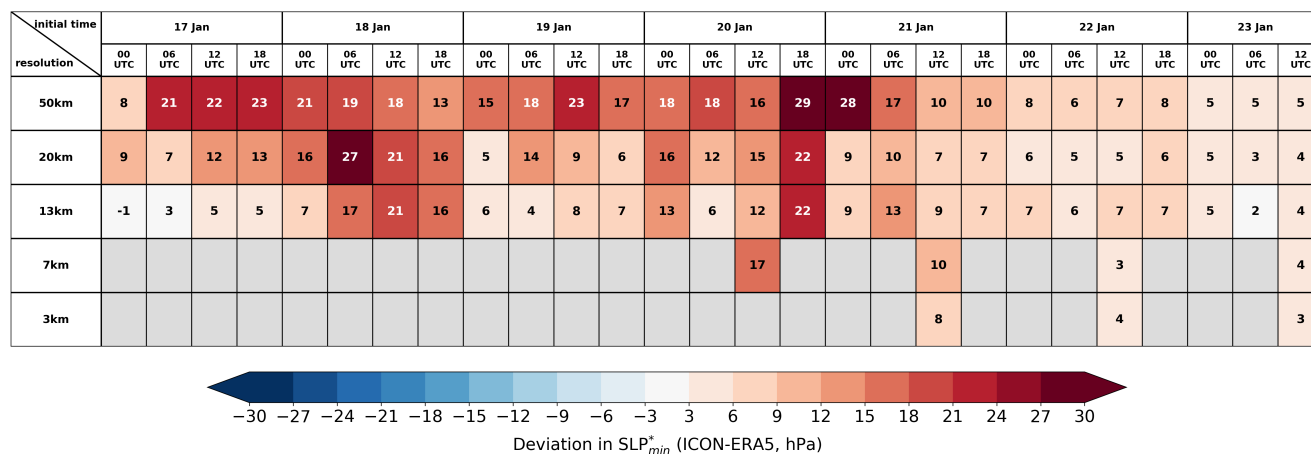


Figure 15. Deviation in SLP_{min}^* between the cyclone in the ICON simulations and ERA5 (hPa) as a function of horizontal model resolution and model initialisation time.

in SLP_{min}^* than the 13 km and 20 km runs at similar initialisation times (e.g., at 12 UTC on 20 January and 12 UTC on 21 January). One explanation for this might be that the 7 km resolution is too coarse to fully resolve convection.

550 To contextualize whether these deviations in cyclone intensity stem from localized structural issues or errors in the large-scale flow, we examine the median deviations in cyclone track and directional track biases across the initialisations (Fig. D1). We find a lead-time dependency, with track deviations systematically decreasing from over 1000 km in the earliest runs to less than 100 km in the final runs. As with cyclone intensity (Fig. 15), this correlation between the magnitude in track deviation and initialisation time is evident (e.g., $r = -0.89$ for the 20 km runs). The spatial misplacement of the cyclone directly accounts
 555 for the higher deviations in SLP_{min}^* in the finer horizontal resolutions relative to the 50 km simulations (Fig. 15). Specifically, during early initialisations, the 13 km and 20 km runs suffer from a severe southward and westward cyclone track displacement (Fig. D1).

Lastly, while we find a tendency for smaller deviations in SLP_{min}^* with higher horizontal grid spacing, higher resolution does not imply a more accurate forecast of SLP_{min}^* . For example, in the ICON simulations initialised at 18 UTC on 20 January,
 560 the three available resolutions at this initial time (13, 20, and 50 km) exhibit large deviations in SLP_{min}^* —demonstrating that increasing spatial resolution alone cannot resolve the intensity discrepancy (Fig. 15). In contrast to the large track deviations on 17-18 January, the simulations initialised at 18 UTC on 20 January exhibit relatively small track deviations (~ 195 km at 13 km, Fig. D1). This shows that, while the cyclone is positioned reasonably well, these initialisations lead to large intensity and deepening-rate deviations. The generally poor performance at these initialisation times is suggested to be attributed to data
 565 assimilation errors that yield incorrect initial conditions. Through upscale error growth, these initial errors quickly spread and prevent the model from capturing the explosive cyclogenesis regardless of the horizontal resolution.



7 Summary and Conclusions

Extratropical cyclones (ETCs) belong to the most impactful weather systems in mid-latitudes. Accurately predicting their exact path, intensity and structure that produce unusual surface hazards is of high relevance. Previous studies have looked into sensitivities of different modelling aspects for characteristics of ETCs and associated features. However, this is, to the best of our knowledge, the so far most detailed investigation combining these aspects using a state-of-the-art numerical weather prediction (NWP) model.

We performed limited-area simulations for high-impact Storm Éowyn—an ETC in January 2025 that rapidly amplified over the North Atlantic and hit the British Isles after undergoing exceptionally strong deepening. Using the ICON model, we investigated the combined sensitivities of the following three different choices for the model configuration and physical processes to the representation of the cyclone and its associated surface winds: (1) horizontal grid spacing (3, 7, 13, 20, 50 km), (2) initialisation time (multiple days around cyclogenesis), and (3) latent heating (LH; control vs. “suppressed LH”). In response to the research questions posed in the introduction, the core findings are summarized as follows:

1. What is the effect of varying horizontal resolution (grid spacings from 50 to 3 km) on cyclone intensity, track, and near-surface wind speeds?

Using the same limited-area domain, initial time, and initial conditions, we find that the developing cyclone shares similar characteristics across all resolution experiments. These include rapid deepening as the cyclone crosses the North Atlantic and a track that agrees reasonably well with the one of ERA5 reanalysis during the development stage.

While higher horizontal resolution tends to produce a stronger cyclone (measured by minimum mean sea level pressure; SLP_{min}^*), the timing of maximum intensity and the cyclone track exhibit resolution-dependent behaviour, which is likely influenced also by the explicit versus parameterised treatment of convection within the simulations. Furthermore, higher horizontal resolution yields slightly stronger near-surface winds, with a noticeable expansion in the area of maximum wind speeds. The cyclone structure (especially mid- and low-level potential vorticity; PV) exhibits more intense, localized features near the cyclone core and its associated fronts. Consequently, we find a positive correlation between the strength of the low-level PV anomaly and the area of cyclone-related high low-level winds, a relationship that strengthens with higher resolution. This suggests that, while coarse resolutions may adequately predict broad surface wind impacts, high-resolution modelling remains crucial for accurately capturing the localized PV dynamics behind the rapidly-deepening cyclone.

2. How does LH influence the structural evolution, intensity, and near-surface winds of Storm Éowyn?

Suppressing LH markedly alters the cyclone’s characteristics compared to the control simulation. Without LH, the cyclone undergoes slower and less intense deepening, exhibiting a higher SLP_{min}^* , reduced low-level PV, and diminished low-level wind speeds. Beyond these cyclone intensity differences, the cyclone within the no-LH simulation shows a major track deviation with a cyclone track shifted to the northwest. The strong jet interaction and downstream ridge building—the latter most likely triggered by diabatic outflow within the warm conveyor belt—are absent in the simula-



tion without LH. This keeps the cyclone embedded in the stronger south-westerly flow along the downstream flank of the trough for longer, forcing a more northward and less eastward propagation. Consequently, the cyclone largely misses the British Isles, which reduces the strongest cyclone-related 10 m wind gusts by over 20 m s^{-1} across the regions heavily affected during the passage of Storm Éowyn in January 2025.

3. How sensitive are the simulated cyclone characteristics to the initialisation time, and how does this sensitivity depend on horizontal resolution and the representation of LH?

We find that the impact of LH on cyclone evolution depends on the initialisation time relative to cyclogenesis. Earlier initialisations yield larger differences in both the track (characterized by a north-westward shift) and the intensity ($\text{SLP}_{\min}^*$), with the diabatic deepening contribution to cyclone intensification ranging from 12 % to 53 %. This occurs because earlier initialisations capture the role of LH throughout the entire life cycle (from genesis to mature stage). In contrast, later initialisations (especially those after cyclogenesis) more directly address how the cyclone evolves when LH is fully suppressed at mid-lifecycle. Because earlier LH contributions are already embedded in the initial conditions, these simulations evaluate the ongoing influence of LH rather than its total impact to cyclone deepening.

Connecting horizontal resolution and initialisation time, a correlation exists between the $\text{SLP}_{\min}^*$ deviation (ICON vs. ERA5) and the initialisation time, demonstrating that later initialisations yield a more accurate representation of cyclone intensity across various horizontal resolutions. Furthermore, across multiple initialisation times, the higher-resolution simulations consistently outperform the coarser ones, reinforcing that the representation of cyclone intensity and track remains inherently dependent on grid resolution.

Although this study focuses on a single high-impact ETC, the insights gained carry broader implications for both NWP and climate modelling. Crucially, this work presents the first suppressed LH experiments using the state-of-the-art ICON model to evaluate cyclone sensitivity to initialisation time in relation to both LH and grid resolution. While many previous studies only compared two configurations, this work systematically evaluates a spectrum of five horizontal grid spacings from a coarse 50 km to convection resolving 3 km —a much finer scale than used in most previous works (e.g., Zappa et al., 2013; Priestley and Catto, 2022; Lee et al., 2026, spanning $\sim 50\text{--}250$ km).

Rather than evaluating model configurations in isolation (e.g., Büeler and Pfahl, 2017; Choudhary and Voigt, 2022), we explore the interconnected sensitivities between grid resolution, LH, and initialisation time. This approach yields two critical takeaways. First, the pronounced sensitivity to initialisation time serves as a cautionary note for studies relying on a single simulation; it highlights that the choice of initialisation can fundamentally affect the quantitative role of physical processes like LH. Second, because our 50 km simulations severely underestimate the intensity of the cyclone and its associated wind hazard, and they miss important structural features, it raises a critical concern for climate models operating at even coarser resolutions. When climate simulations with grid spacings of 50 km or coarser are used to investigate high-impact extratropical cyclones, then these limitations in the models' capability of realistically capturing the track and intensity of such systems must be taken into account.



While these findings advance our understanding of the model configuration sensitivity to cyclone characteristics, several limitations should be acknowledged. Primarily, because this study relies on a single high-impact cyclone, the identified sensitivities may vary across different cyclone cases and types. Our current research expands upon this single-case framework by systematically analysing a collection of multiple historic, high-impact ETCs. Furthermore, to analyse the robustness of our findings to the choice in model formulation (numerics, physics parameterisations), this expanded analysis will incorporate additional state-of-the-art NWP models. This multi-ETC, multi-model approach will provide a more generalized and robust assessment of how resolution, initialisation time, and LH interact for the simulation of high-impact ETCs.

Code and data availability. We used the open-source ICON model code version 2025.04 for our simulations. The ERA5 re-analysis data is available on the Copernicus Climate Change Service (C3S) Climate Data Store: <https://doi.org/10.24381/cds.143582cf> (Hersbach et al., 2017). IFS analyses were downloaded from the Meteorological Archival and Retrieval System (MARS) of ECMWF. The SLP and 10 m wind gust fields from the ECMWF IFS ensemble forecasts and the scripts used to produce the analyses can be shared on request from the authors.

Supplement This manuscript has a supplementary.

Author contributions. SH performed all ICON simulations, analysed them and prepared the figures. HW designed the project. HW and LP gave important guidance and were involved in discussions. SH wrote the original draft and HW and LP provided feedback.

Competing interests. HW is a member of the editorial board of Weather and Climate Dynamics. The authors have no other competing interests to declare.

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Appendix A: Sensitivities of cyclone intensity, track and properties to changes in vertical grid spacing

The number of vertical levels in our ICON setup (Sect. 2.2) is varied to check whether this would impact the simulated cyclone characteristics, such as intensity, track, vertical PV structure and associated near-surface winds and precipitation. We therefore selected three different numbers of vertical levels (recall that as model top we selected 30 km): 45 levels, 90 levels (this is the number of levels we used across the study) and 180 levels for a fixed horizontal grid spacing of 13 km (see Tab. 1).

Vertical resolution affects our selected cyclone properties, but these changes are minor compared to those driven by horizontal resolution. Doubling the number of vertical levels leads to only a minor increase in cyclone intensity of less than 1 hPa, yielding a slightly closer match to ERA5 (Fig. A1a). Conversely, halving the number of vertical levels degrades the maximum intensity representation, weakening the simulated cyclone by just over 1 hPa. The cyclone track shows no sensitivity to vertical resolution changes (Fig. A1b). It is only single time step jumps which are rather an artefact of the tracking algorithm than actual meaningful differences. Increasing the vertical resolution leads to slightly stronger low-level PV values, indicating a more pronounced PV tower linked to the cyclone (not shown). In terms of surface hazard, cyclone-related near-surface wind speeds (10 m wind speed) and precipitation sums increase consistently as vertical resolution becomes finer. However, both metrics exhibit low overall sensitivity to vertical resolution, increasing monotonically by less than 1.2 % for the grid refinement from 45 to 180 levels (not shown).

Appendix B: Sensitivity of cyclone intensity differences to regridding and metric choice

Here, we briefly address whether calculating the metrics on the original grid spacing versus conservatively re-gridding to the coarsest resolution (50 km) affects the outcomes, or whether it matters which intensity metric we use. For the former, we find that regridding the simulation output to a common coarse resolution leads to a small but overall negligible decrease in intensity measured by SLP_{min}^* (of about 1-2 hPa), which is larger the higher the grid spacing (Fig. B1a). This aligns conceptually with Priestley and Catto (2022), who reported a systematic but small ~ 1.4 hPa deeper average SLP_{min}^* when moving from low- to high-resolution model configurations. Using relative vorticity at 850 hPa is the most used alternative metric to track and describe the intensity evolution of ETCs (e.g., Ulbrich et al., 2009; Hodges, 1994). Instead of tracking the cyclone again using the method of Hodges (1994), we simply analyse the 850 hPa relative vorticity within a 200 km radius around the cyclone centre. Using this alternative measure shows similarly minor differences in intensity when averaged across the core area for the original and remapped resolutions (Fig. B1b); however, these values are again sorted by resolution, where finer grids yield higher mean relative vorticity. A slightly different picture emerges when looking at the non-regridded maximum relative vorticity around the cyclone centre (Fig. B1c), which yields a strict intensity ordering by resolution and large discrepancies in magnitude. This is to be expected, given that relative vorticity depends on the resolution of spatial gradients. However, even when re-gridded to the coarsest resolution, the ordering persists: the 3 km run maintains the highest intensity and the 50 km run the lowest. In summary, the SLP-based and relative vorticity-based approaches to determine ETC intensity yield similar impression about the accuracy of the cyclone evolution in the different experiments.

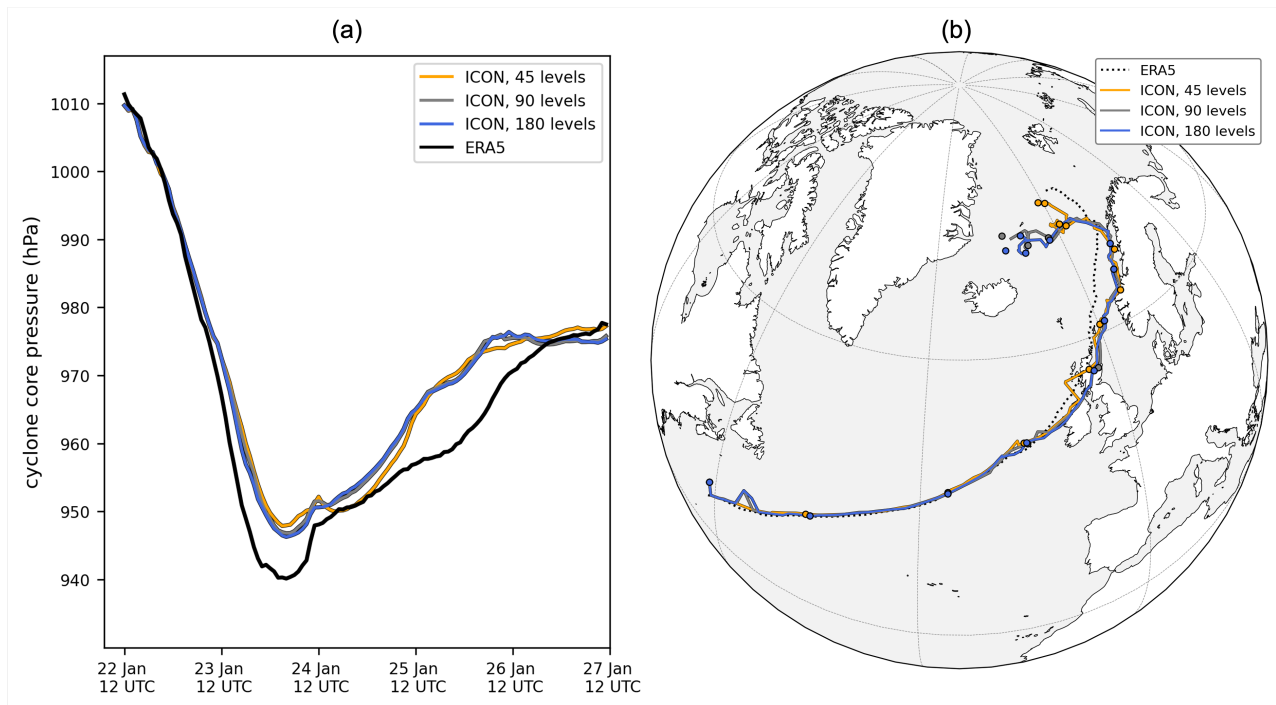


Figure A1. (a) Evolution of SLP* as shown in in Fig. 6a, but for simulations with a horizontal resolution of 13 km and varying number of vertical numbers, corresponding to changes in vertical resolution. (b) Corresponding cyclone tracks with positions of the storm every 12 h.

Appendix C: Understanding the different timing in reaching SLP_{min}^*

The interested reader might have spotted that the cyclones in the five simulations reach their maximum intensity, measured as SLP_{min}^* , at slightly different times, and, given differences in the tracks, at different locations. The cyclone in the 50 km simulation reaches peak intensity first, followed 1-2 h later by the peak in the 20 km simulation, then another 1-2 h later by the cyclone simulated with 13 km grid spacing. This time actually agrees with the intensity maximum in the ERA5 track (Fig. 6a). For the two convection-permitting simulations (3 and 7 km), peak intensity is reached around 7 h after the peak in the 13 km simulation and in ERA5, leading to a significant timing difference between the coarser and the high-resolution simulations. This leads to relatively large deviations in cyclone position at the time of maximum intensity between the coarse and high-resolution tracks of 200-500 km (Fig. 6c).

A better understanding in these differences can be gained from time-height cross sections of PV and diabatic heating along the centre of the tracked cyclone (Fig. C1). Multiple differences between the coarser and higher resolution experiments are evident:

1. For the cyclone in the three coarser simulations (50, 20, and 13 km), the SLP_{min}^* coincides qualitatively well with the maximum amplitude of the PV tower and in particular the maximum intensity of the low-level PV anomaly (Fig. C1a-c).

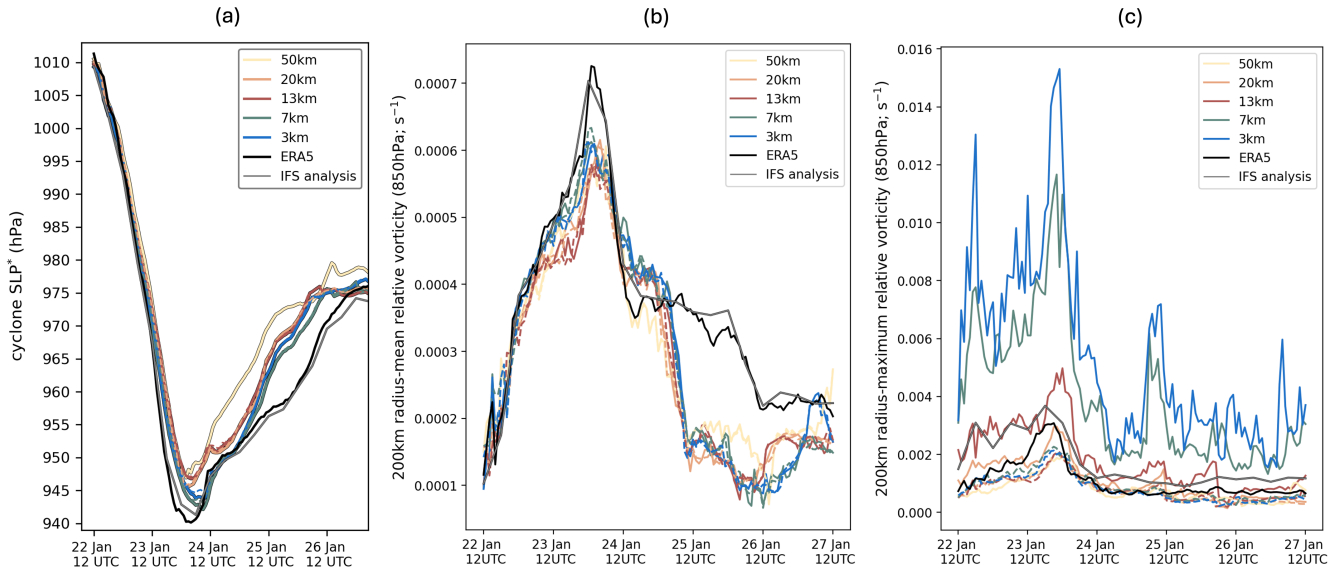


Figure B1. (a) Evolution of SLP* as shown in Fig. 6a, but shown here for the SLP field using the native grid resolution (solid) versus when interpolated to the grid of the 50 km simulation (dashed). (b) Evolution of relative vorticity at 850 hPa (s^{-1}), averaged over the area that encompasses a 200 km radius around the cyclone centre. Solid lines again for the calculation using the native grid resolution and dashed lines for the interpolated fields on the coarsest resolution. (c) Same as panel b, but taking the maximum value within the 200 km radius instead of a spatial mean.

However, for the high-resolution simulations, the PV tower and specifically also the low-level PV are strongest 6-8 h before the SLP*_{min} is reached (Fig. C1d-e).

2. SLP*_{min} is reached in the 20 and 13 km simulations when the cyclone is located west of the British Isles, just before landfall, which implies increased surface friction (horizontal bar in lower part of the panels in Fig. C1 shows land fraction). The cyclone in the 50 km simulation reaches peak intensity west of Ireland and at that time is hardly affected by increased friction over land. In contrast, the cyclones in the high resolution simulations experience their highest intensity ~ 6 h after the cyclone moves over land. It is interesting that these cyclones intensify further as their centre moves over land.

3. In the early phase of the cyclone life cycle, diabatic heating maximizes around 500 hPa across all resolutions (Fig. C1). However, the subsequent evolution of diabatic heating near the cyclone centre varies significantly until the cyclone deepening stage, with coarser resolutions producing stronger area-averaged heating throughout the vertical column. In the three coarser simulations (13, 20 and 50 km), diabatic heating extends throughout the lower-tropospheric layer up to 500 hPa and reaches its maximum magnitude shortly before or at the time of SLP*_{min} (Fig. C1a-c). In contrast, diabatic heating is restricted to the 800-500 hPa layer and the maximum diabatic heating signals occur several hours before peak cyclone intensity in the high-resolution simulations (Fig. C1d-e).

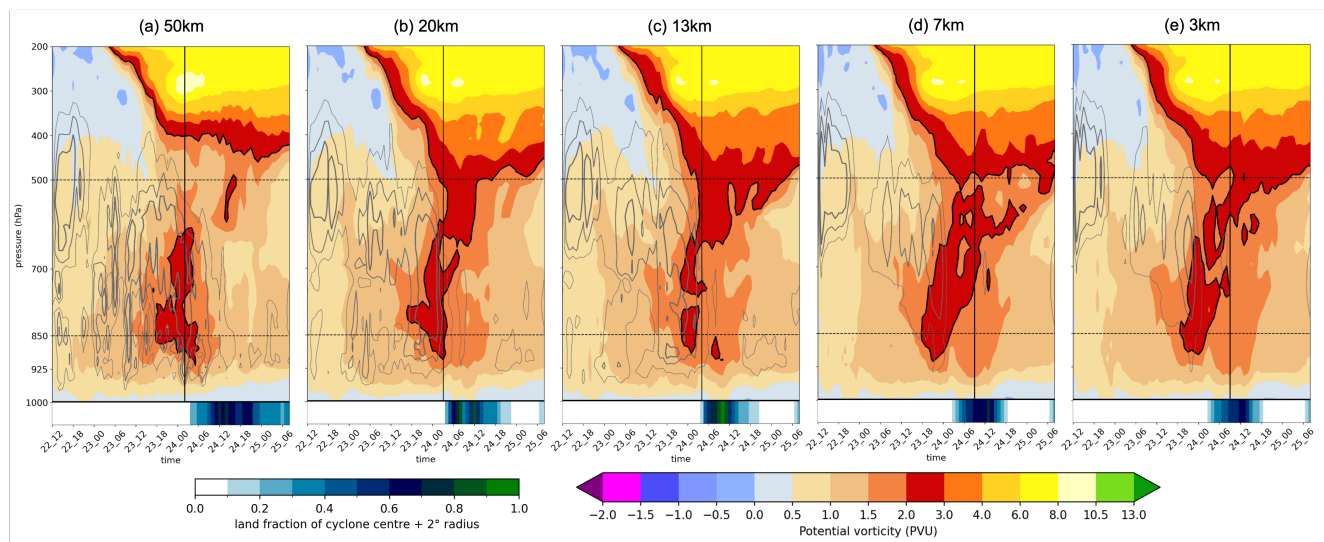


Figure C1. Time-height cross-sections of Storm Éowyn showing PV (shading; right colourbar, black bold contour for 2 PVU), LH rate (from microphysics and convection schemes; grey contour lines for 0.02, 0.04, and $0.06 \cdot 10^{-2} \text{ K s}^{-1}$). Values are horizontally averaged within a 2° radius around the cyclone centre for ICON simulations with different horizontal resolutions: (a) 50 km, (b) 20 km, (c) 13 km, (d) 7 km, and (e) 3 km. Vertical black lines mark the time of $\text{SLP}^*_{\min}$ along the cyclone track. The horizontal bar in the lower part of the figure shows the land fraction averaged within a 2° radius around the cyclone centre.

These differences can partially explain the shift in the timing of the cyclone's intensification across the simulations. In the coarser simulations, parameterised convection creates an intense and continuous burst of diabatic heating that goes along with a collocated drop in surface pressure. As in these simulations convection is favoured over the ocean and inhibited as the system approaches land, the peak diabatic heating, maximum PV tower strength, and $\text{SLP}^*_{\min}$ all co-occur when the cyclone is still offshore, i.e., just before hitting land west of Ireland. It appears that in these simulations, the timing of cyclone intensity is strongly determined by diabatic low-level PV production.

Appendix D: Discussion of wind gust differences between ICON simulations and IFS ensembles

Area-mean 10 m wind gusts along the western coast of Ireland show strong sensitivity to the initialisation time in ICON (Fig. 14b). Often the highest wind gusts are outside the interquartile range of the IFS ensemble, with stronger gusts in ICON compared to the IFS. This can have multiple reasons:

1. Horizontal grid spacing is different: The IFS ensemble runs on 9 km, but is stored on a coarse 0.25° grid, while our 13 km ICON simulations are interpolated on a 0.125° grid. Horizontal resolution is particularly critical when analysing small-scale, high-wind features linked to ETCs, such as sting jets (e.g., Clark and Gray, 2018).

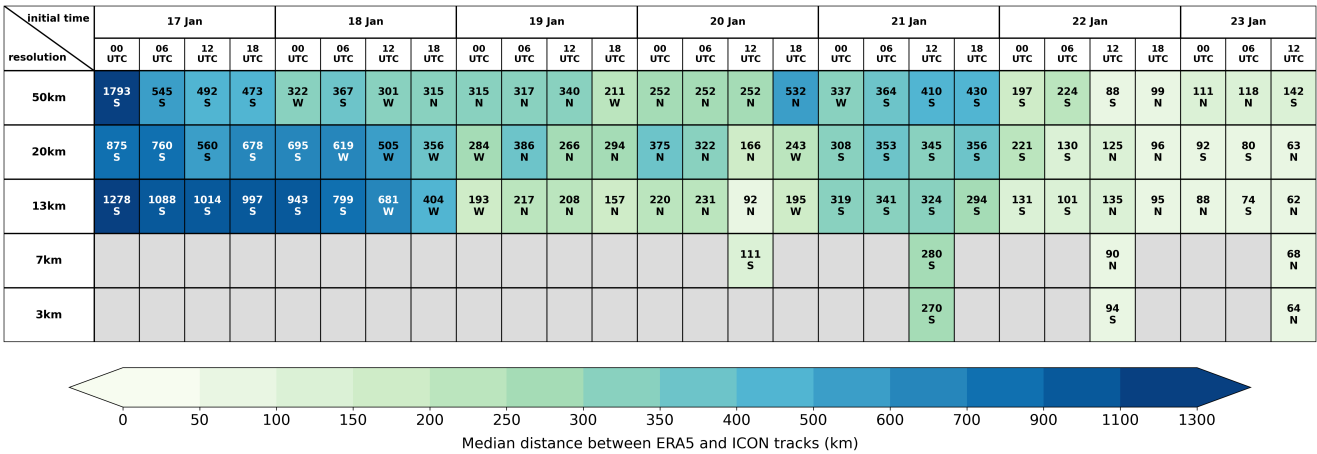


Figure D1. Median displacement error (haversine distance) between the cyclone tracked in the ICON simulations and the ERA5-based track (km, numbers in table), for the period 23 January 00 UTC (or later, depending on initialisation time) to 25 January 00 UTC. The labels 'W', 'E', 'N', 'S' correspond to the most frequent direction bias for the considered time period. Note the non-uniform colourbar steps.

2. Wind gusts are defined and determined differently across models. ICON calculates gusts using surface-layer turbulent kinetic energy (e.g., Schulz, 2008), whereas ECMWF models rely on surface friction velocity and convective wind shear (e.g., Panofsky et al., 1977). Between the ECMWF products, the high-resolution IFS ensemble captures sharp, localized peaks, while ERA5's coarser grid smooths those peak gusts out.
3. The exact track strongly determines the wind impact over the west coast of Ireland. As discussed above, early initialisation times (e.g., 00 UTC on 17 January to 00 UTC on 18 January) indicate a track that is shifted north of the British Isles (Fig. D1 and Fig. D2), hence lower wind gusts over Ireland compared to ERA5. The same applies to the very much southward-shifted cyclone in the 18 January 12 UTC simulation, especially since the highest wind gusts occur predominantly to the south of the cyclone centre.
4. Apart from the track of the cyclone relative to the British Isles, the intensity plays a role here too. For example, the cyclone within the run started at 00 UTC on 20 January might show high similarities with the track in ERA5, however its intensity was underestimated by nearly 15 hPa.

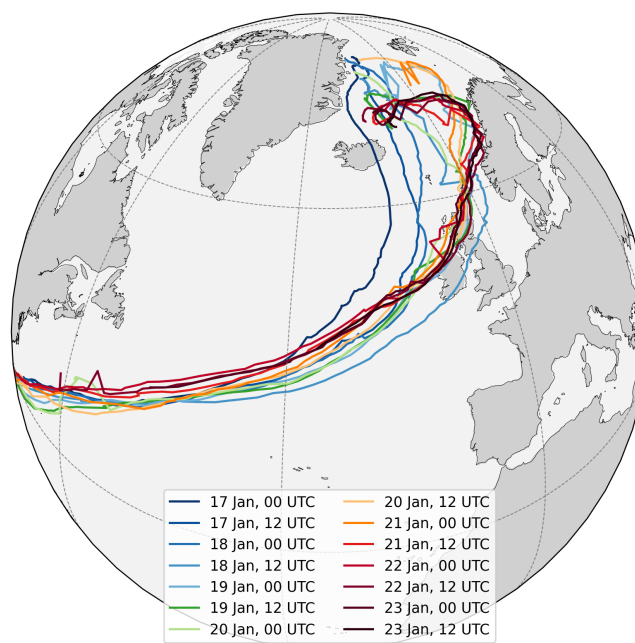


Figure D2. Tracks of 13 km ICON simulations of Storm Éowyn with varying initialisation times (as indicated in legend).

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